the Energy to Lead

Natural Gas Variability in California: Environmental Impacts and Device Performance

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Gas Technology Institute

- 2010 California Energy and Air Quality Virtual Conference
- UC-Irvine
- November 2, 2010

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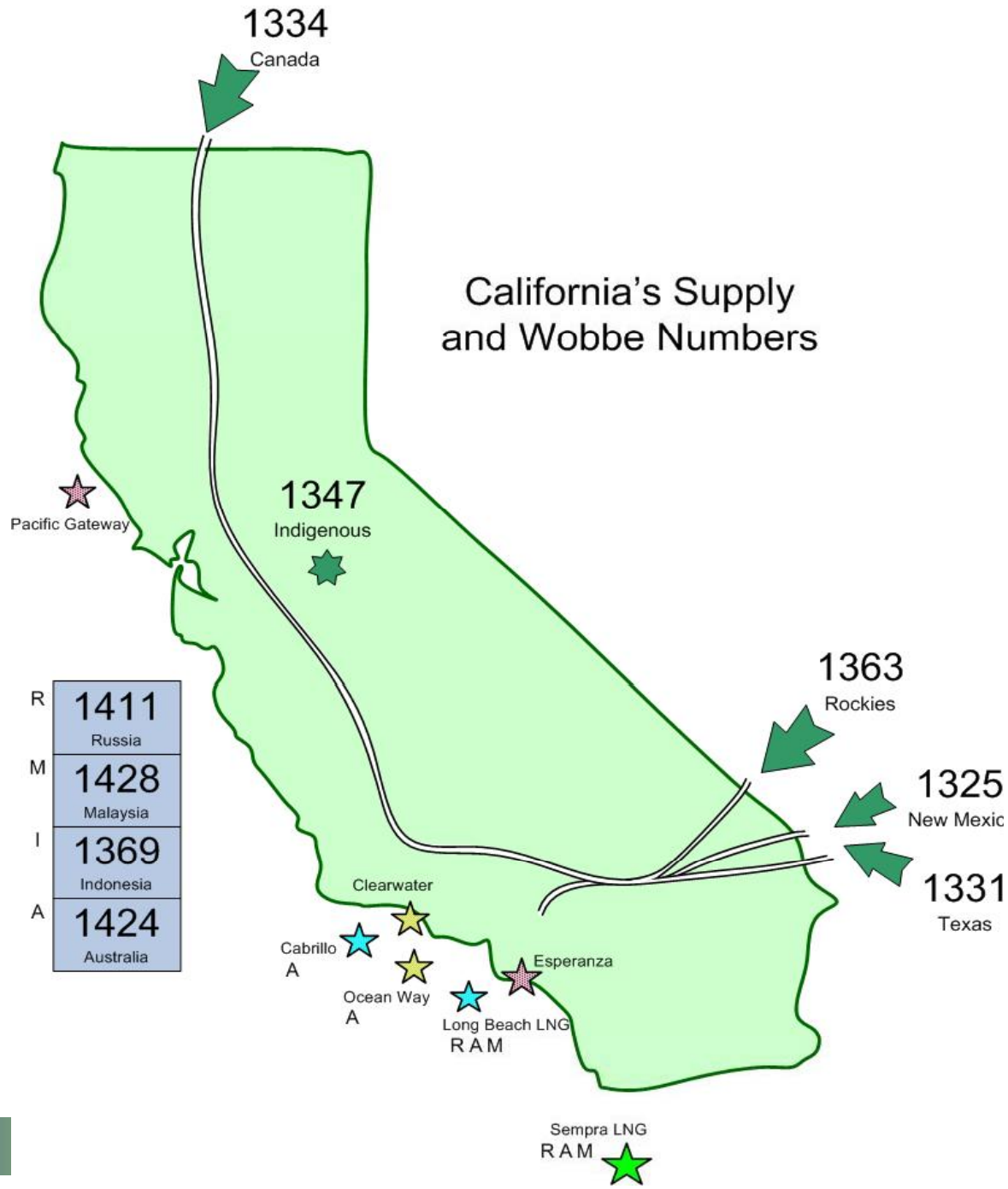
Overall Program Objective

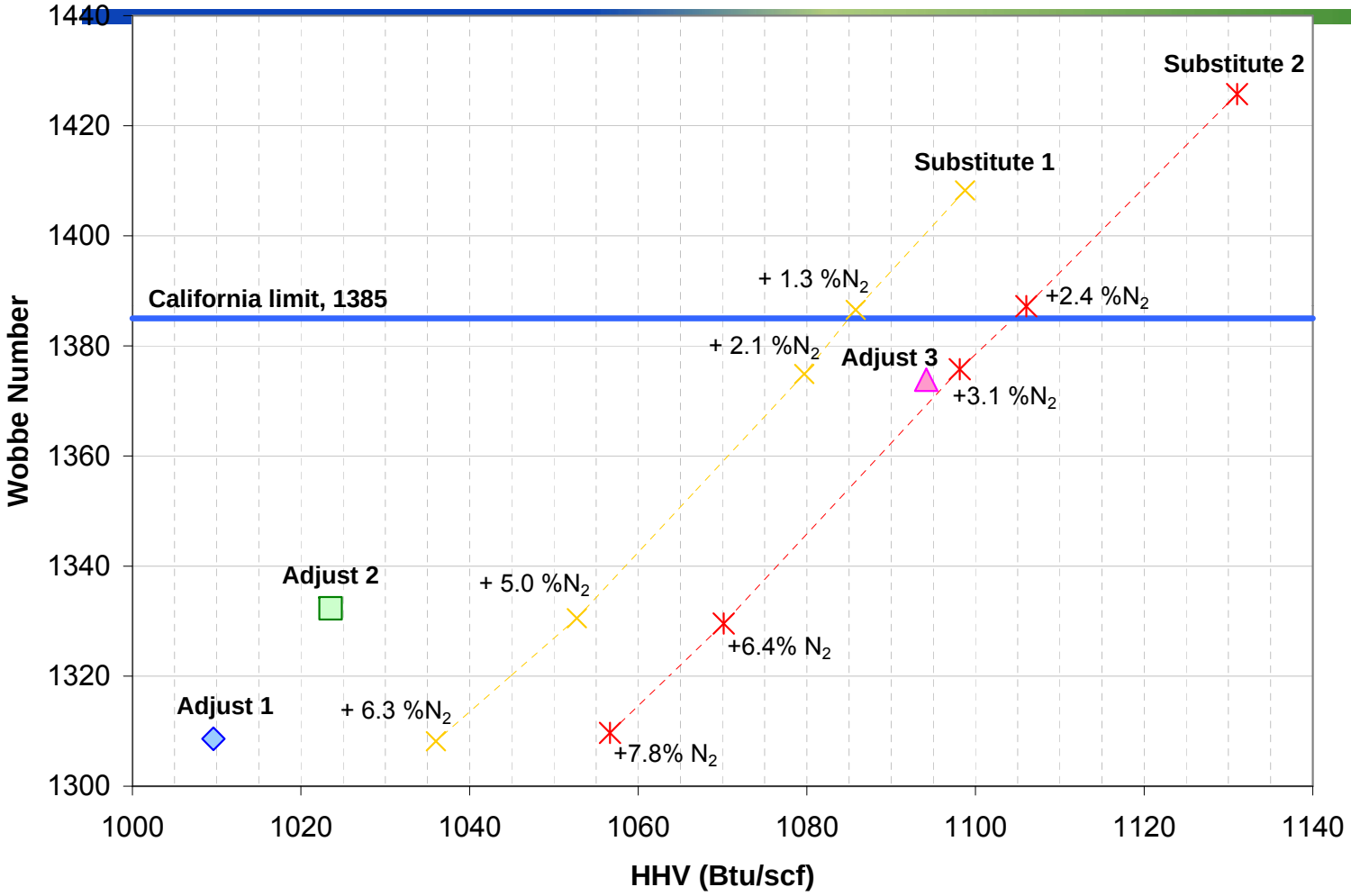
- To provide information to policymakers, regulators and industry such as on the potential safety, performance and air quality impacts of increased variability in the California natural gas supply, and specifically related to the use of LNG.
- Industrial combustion systems – GTI
- Commercial cooking appliances - GTI
- Appliances, indoor and outdoor air quality, range hoods - LBNL

California Gas Variability

- Data from 2004
- Only the Sempra LNG terminal in Baja was built



Test Gases Selected for Industrial Burner and Cooking Appliance Tests



Gas Blends

		Composition							HHV* (Btu/scf)	Wobbe Number*
1	Adjust Gas 1 (A1)	%C1	%C2	%C3	%C4	%C5+	$\%N_2$	$\%CO_2$	1010	1308
		93.2%	2.52%	0.41%	0.16%	0.08%	2.69%	0.92%		
2	Adjust Gas 2 (A2)	%C1	%C2	%C3	%C4	%C5+	$\%N_2$	$\%CO_2$	1024	1332
		94.5%	2.55%	0.42%	0.14%	0.10%	1.36%	0.93%		
3	Adjust Gas 3 (A3)	%C1	%C2	%C3	%C4	%C5+	$\%N_2$	$\%CO_2$	1097	1375
		90.5%	2.45%	3.40%	1.38%	0.10%	1.30%	0.89%		
4	Substitute Gas 1 (S1)	%C1	%C2	%C3	%C4	%C5+	$\%N_2$	$\%CO_2$	1099	1408
		92.4%	4.90%	1.90%	0.79%	0.00%	0.00%	0.00%		
5	Substitute Gas 2 (S2)	%C1	%C2	%C3	%C4	%C5+	$\%N_2$	$\%CO_2$	1130	1425
		89.4%	7.10%	2.50%	1.04%	0.00%	0.00%	0.00%		

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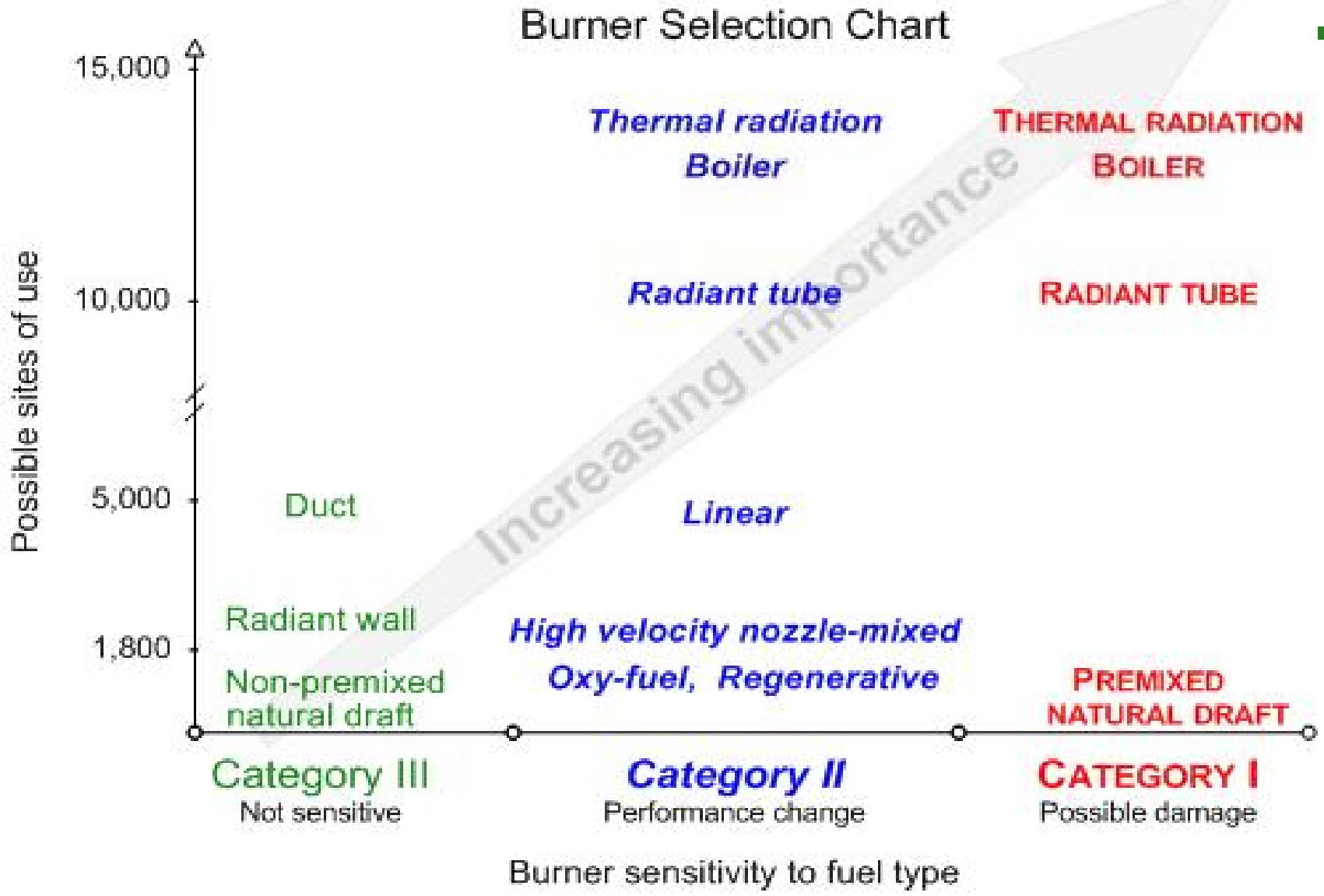
Industrial Burner Classification Criteria

1. Mixing Type
2. Fuel Type
3. Oxidizer Type
4. Draft Type
5. Heating Type
6. Burner Geometry

Industrial Burner Types & Burner Applications

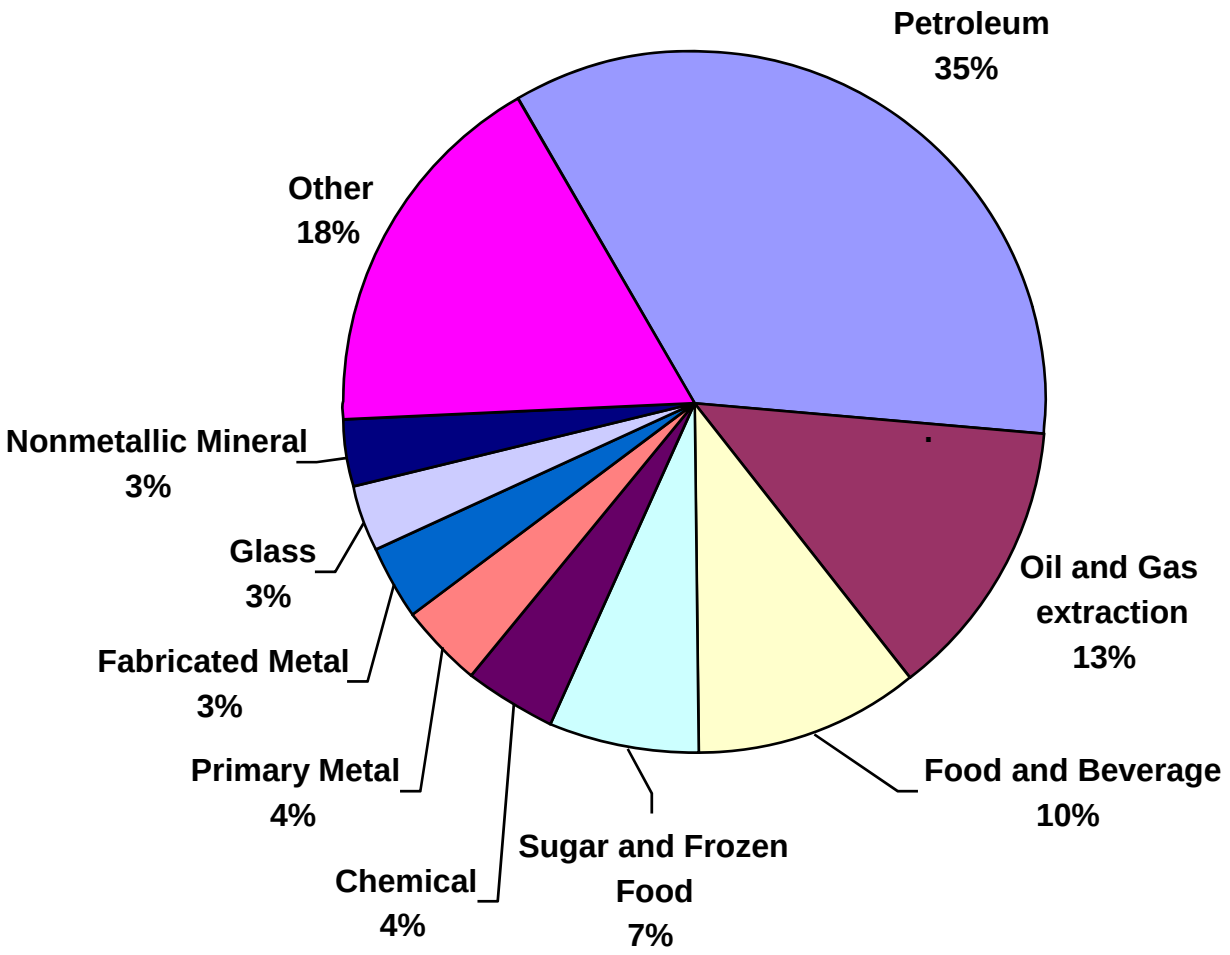
1. Radiant Burners
2. High Velocity Burners
3. Regenerative Burners
4. Natural Draft Burners
5. Boiler Burners
6. Linear Grid / In-Duct Burners
7. Oxygen Enhanced / Oxy-Fuel Burners
8. Flare Burners

CA Burners and Sensitivity



Industrial Natural Gas Demand

by Sector in California (2000-2004)



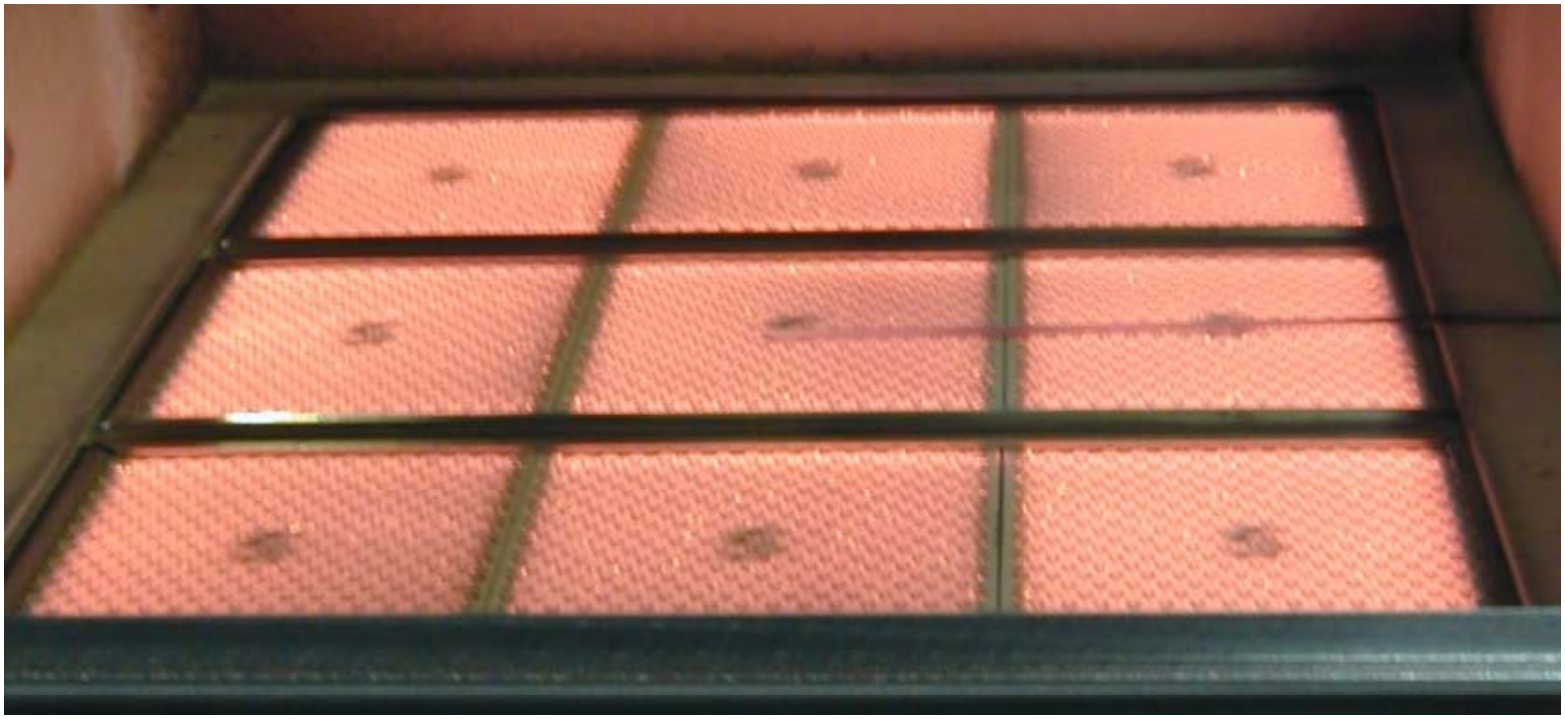
Source: California Energy Commission

Burners Selected for IX Testing

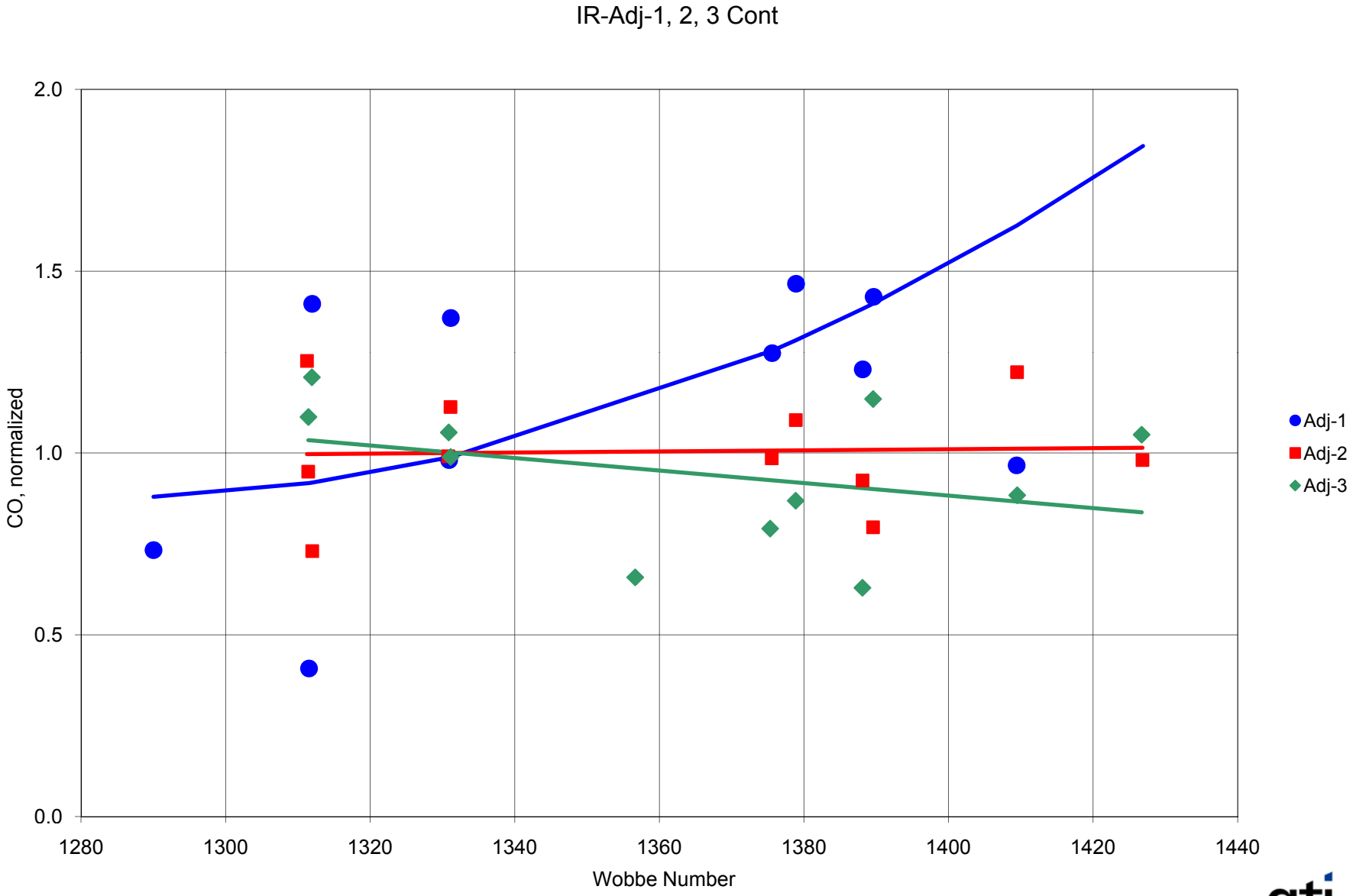
- All relevant types are covered
- Top sellers – by market presence

Manufacturer	Model Name	Comment	Control	Capacity, MMBtu/hr
Radiant Burners				
North American	Evenglow	Radiant Tube	Modulating +Pressure Balance	0.02 - 0.5
Maxon	Radmax	Radiant Panel	On/Off + Venturi mixer	0.025 per head
Bloom Engineering	2320	Recuperative	Modulating	0.4 - 0.5
Boiler Burners				
Powerflame	C1-G-12	Turndown 10:1	Cam linkage + O_2 Trim	2-14.7
Cleaver-Brooks	SB-200-080-150	Low NOx Packaged System		80HP
LAARS	Mighty Term II	Hydronic Boiler	Staged Control	0.5 – 2.0
Linear/Grid/Duct Burners				
Flynn Burner	Pipe	Linear Burner (baking)	Modulating +Venturi mixer	0.04 per inch
Oxygen Enhanced Combustion				
Eclipse	PrimeFire 300	High Luminosity	On/Off + Pressure Balance	0.5 – 8.0
Regenerative Burners				
Bloom Engineering	1150	Nozzle-Mixed type	Modulating +Pressure Balance	To be tested
Nozzle Mixed Burners				
Eclipse Combustion	ThermJet	High Velocity	Modulating +Pressure Balance	0.15-20

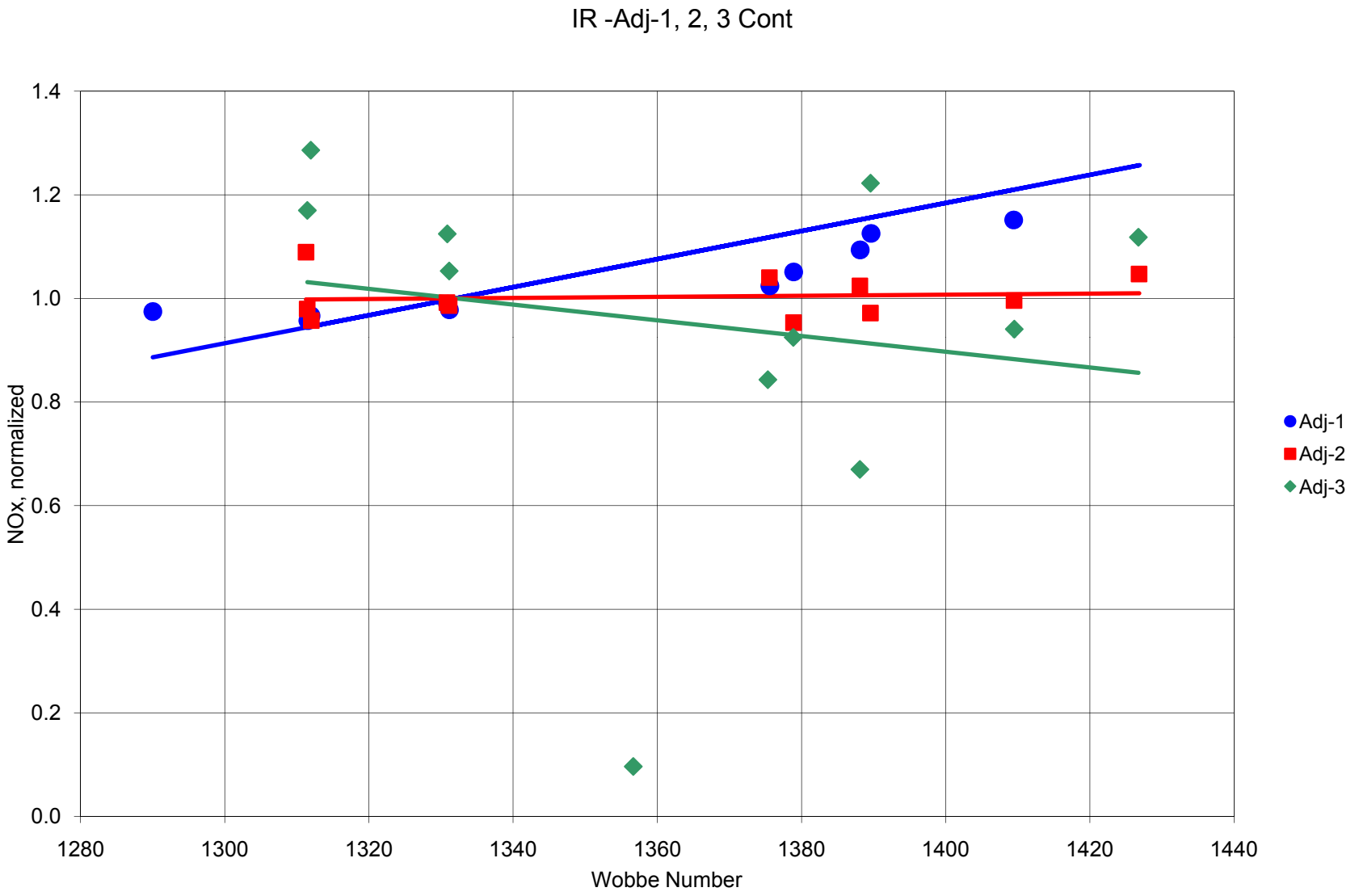
Radiant Surface IR Burner
Maxon
Radmax Radiant Panel
Plastics, cooking, uniform heating



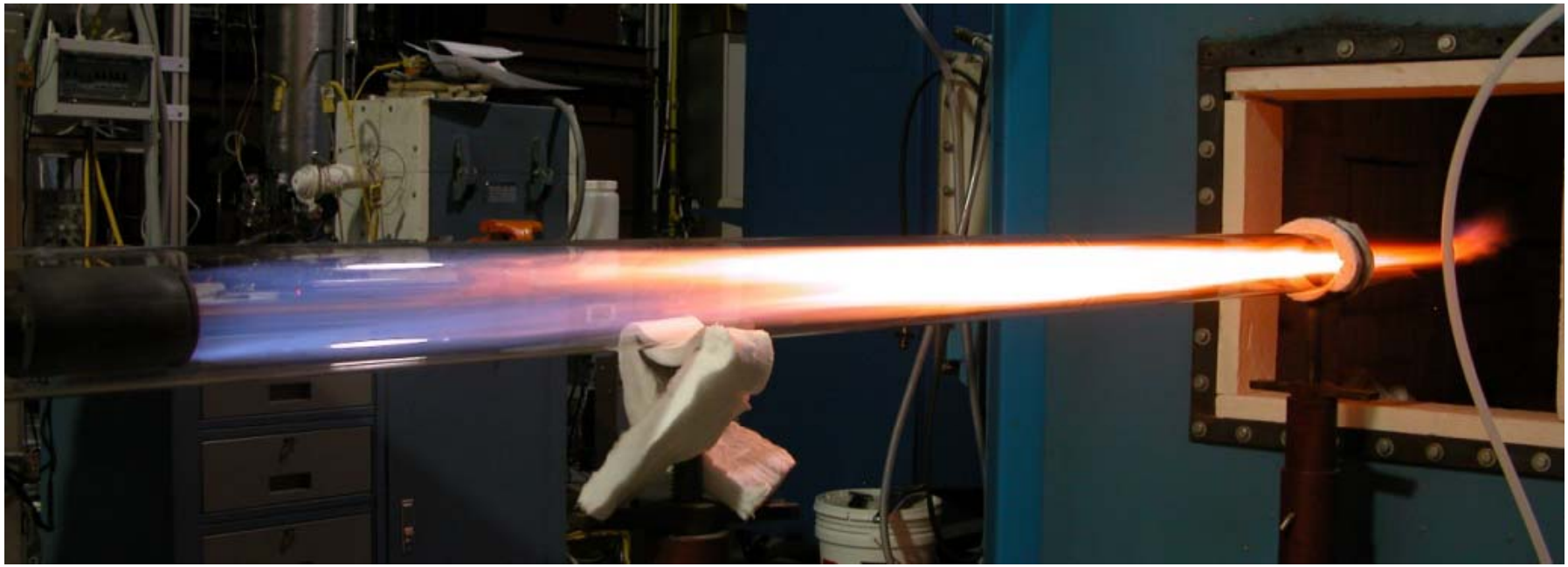
Maxon IR Surface Burner



Maxon IR Surface Burner

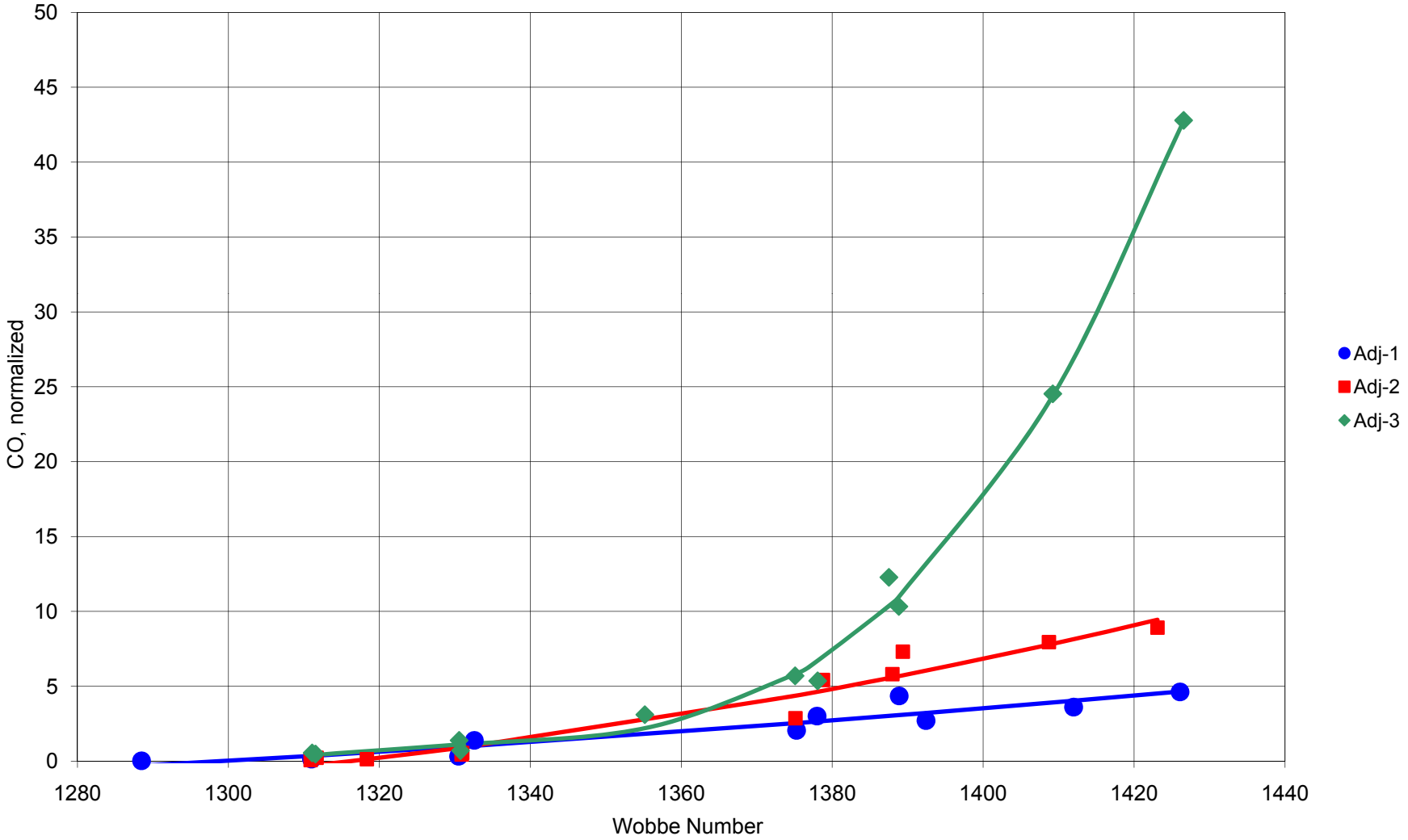


Radiant Tube
North American Mfg.
Evenglow
Metals heat treating

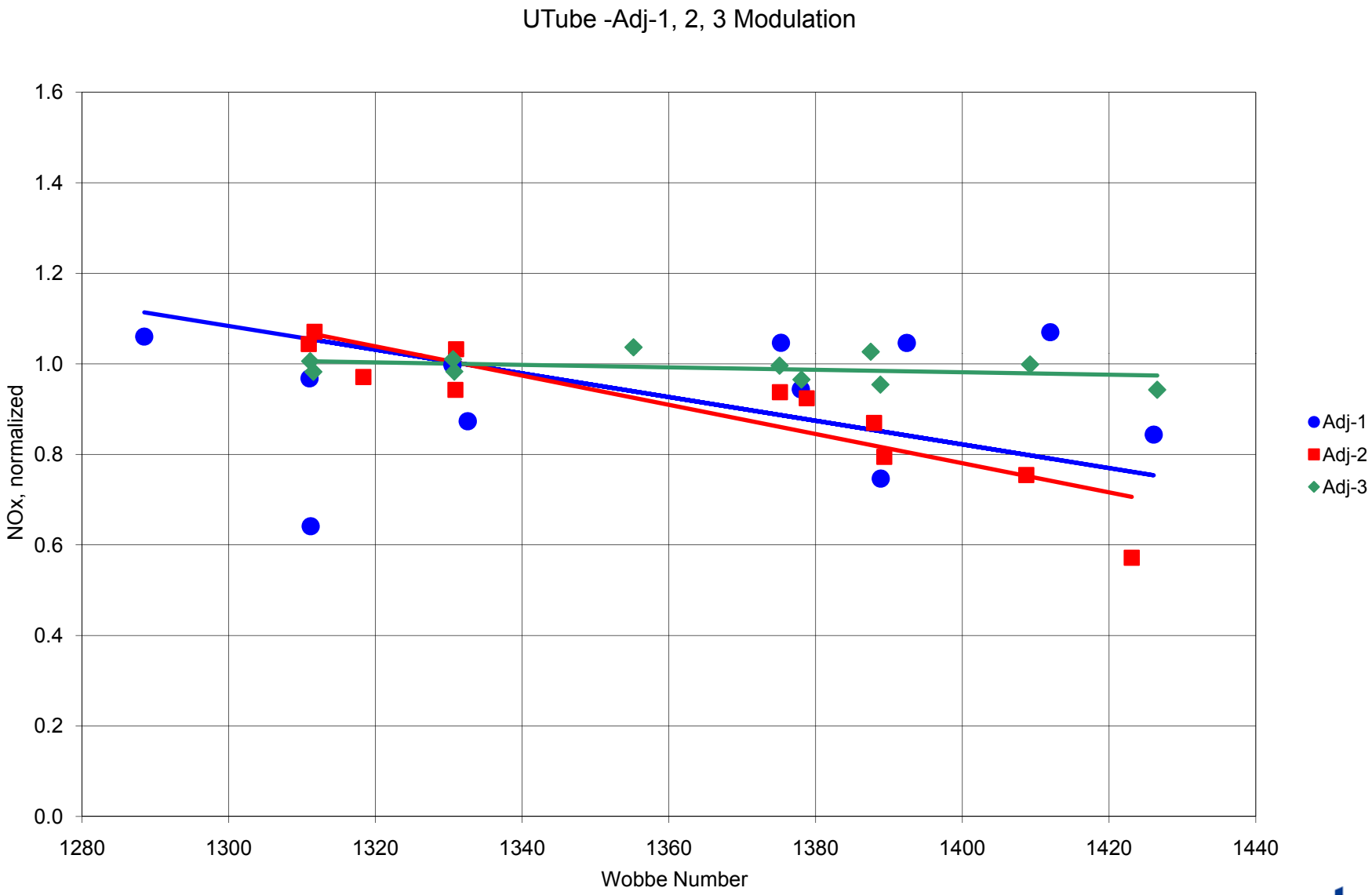


North American Evenglow Rad. Tube

UTube-Adj-1, 2, 3 Modulation

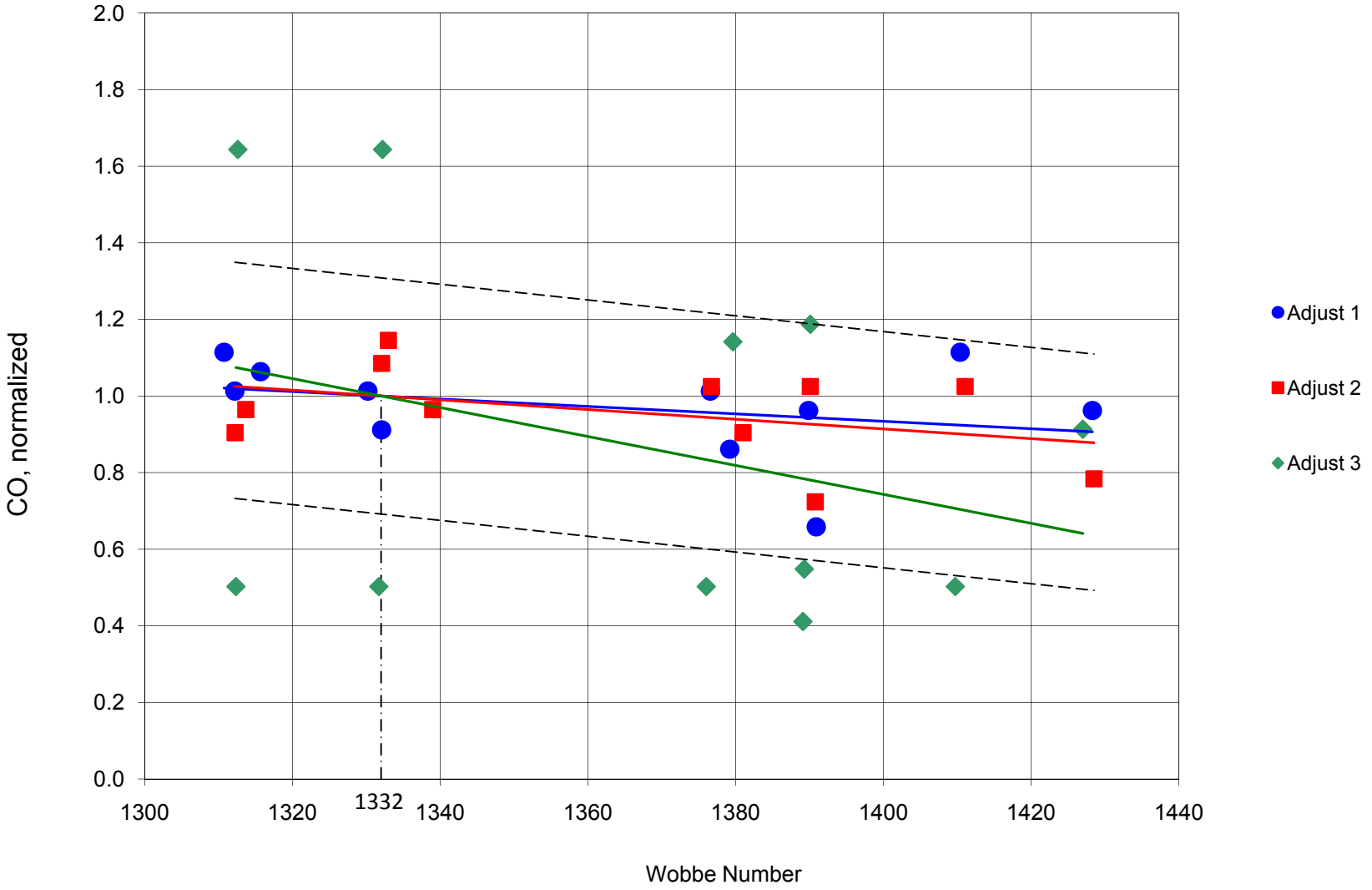


North American Evenglow Rad. Tube

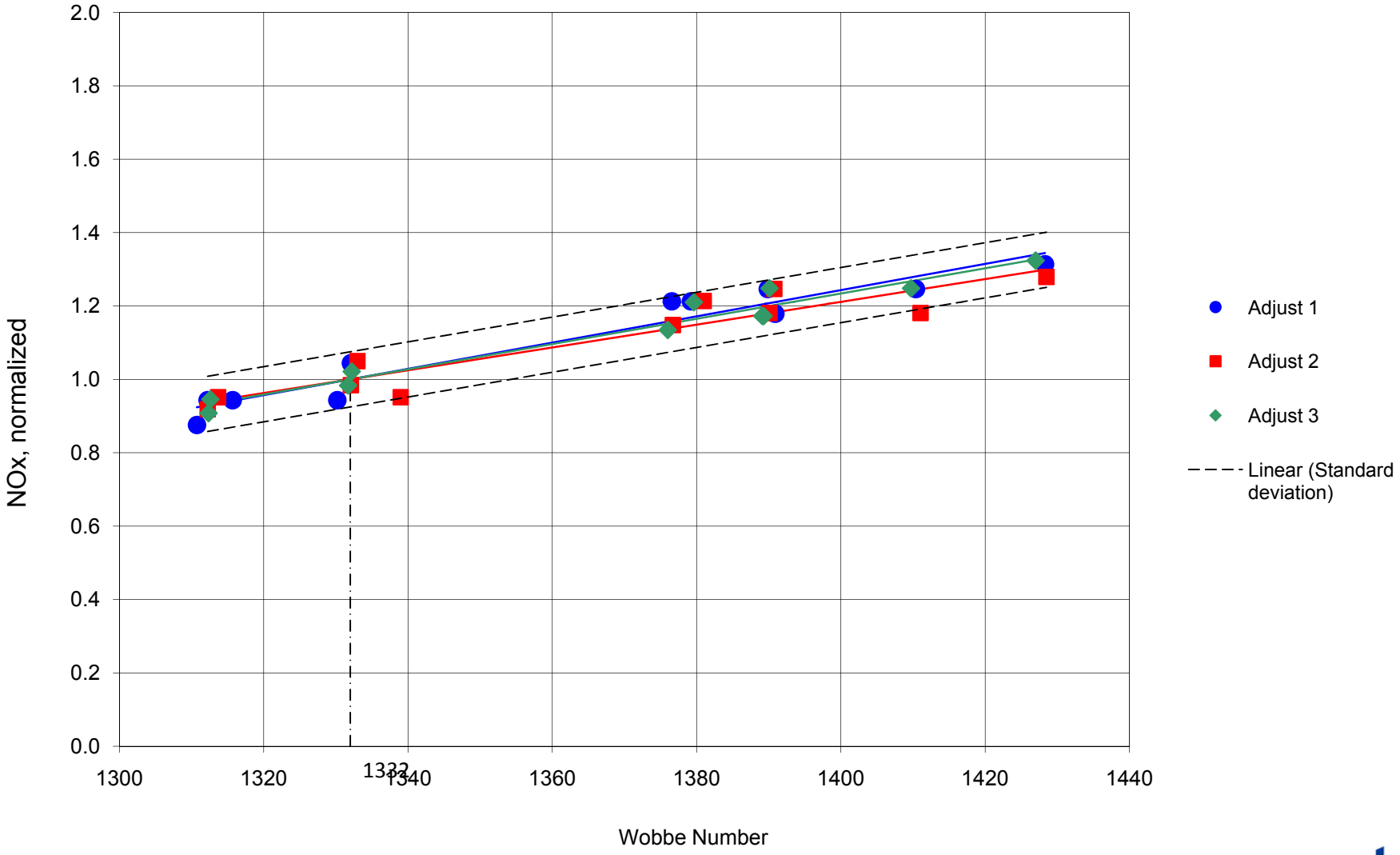


Linear/Grid/Duct Burners
Flynn
Pipe burner
Commercial cooking / air heating

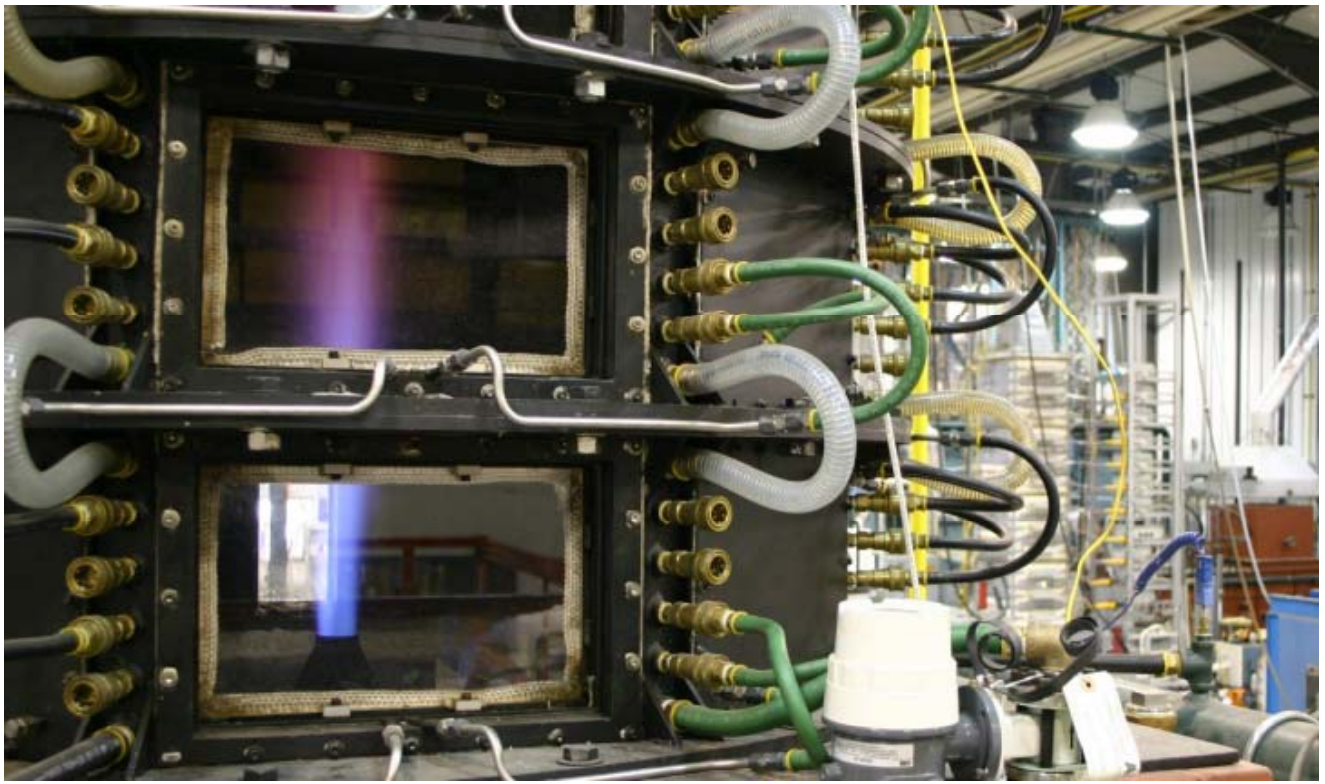
Linear Burner - Modulating



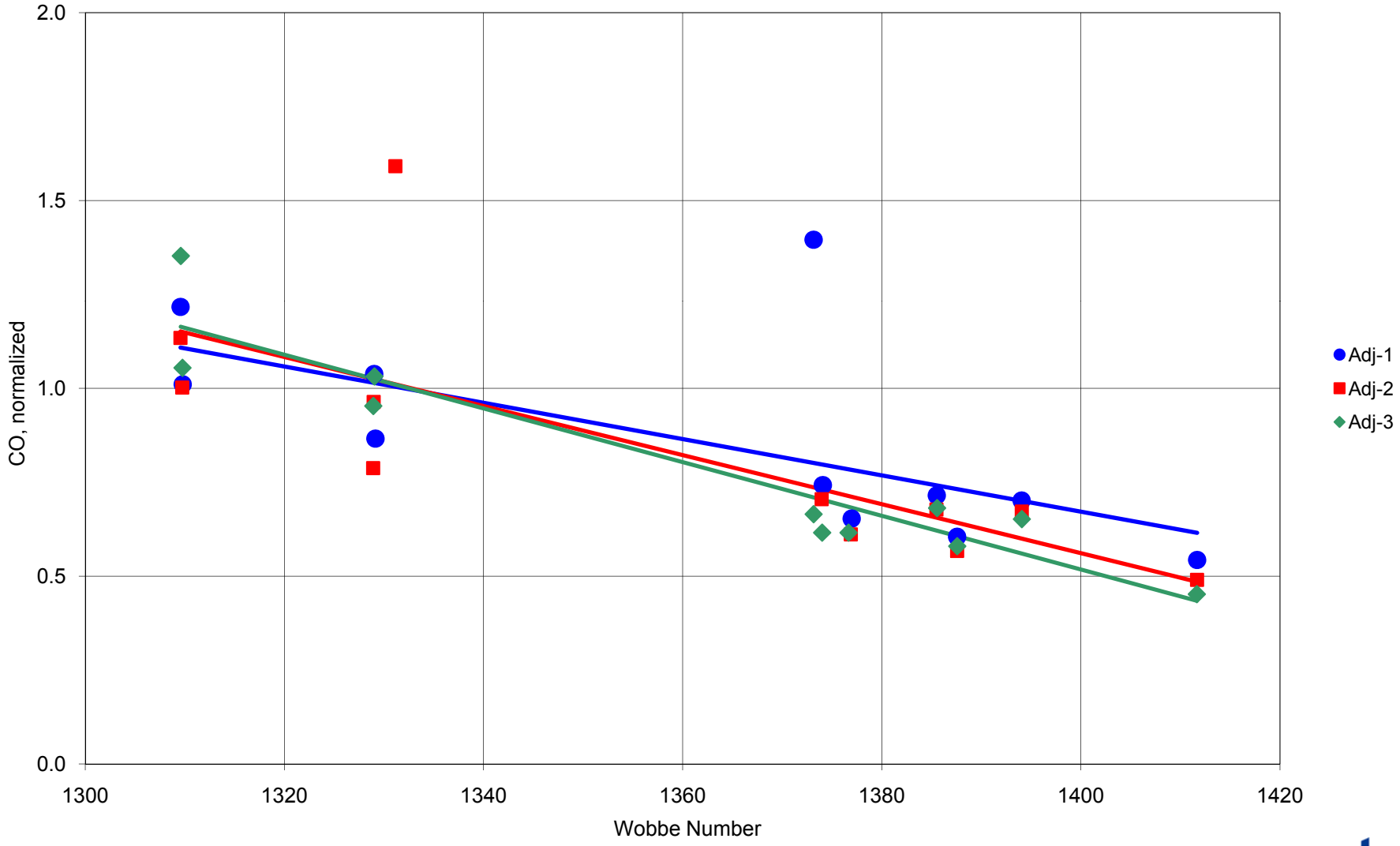
Linear Burner - Modulating



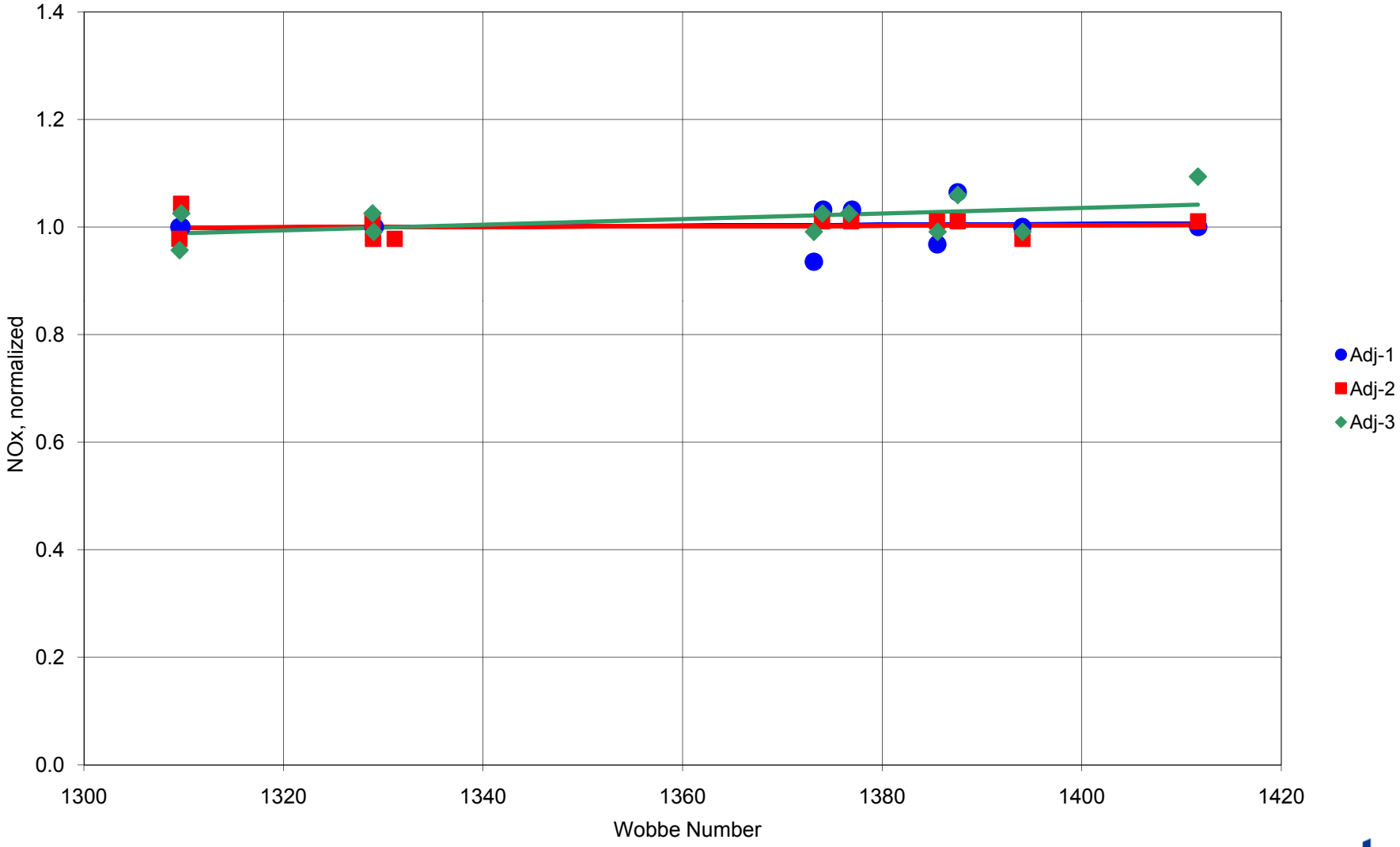
High Velocity Nozzle Mixed Burner
Eclipse
Therm Jet
High temperature processes



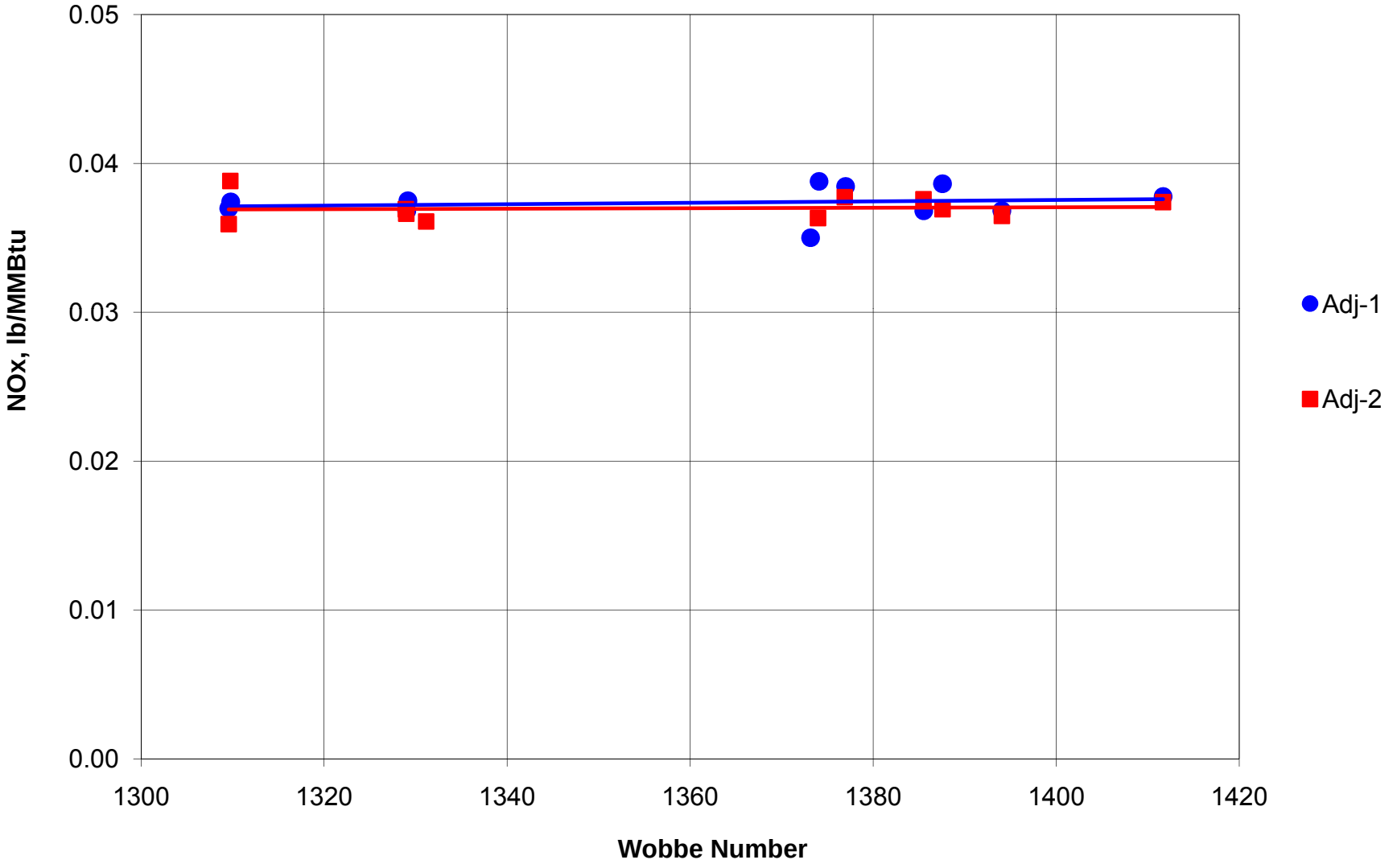
ThermJet-Adj-1, 2, 3 Cont



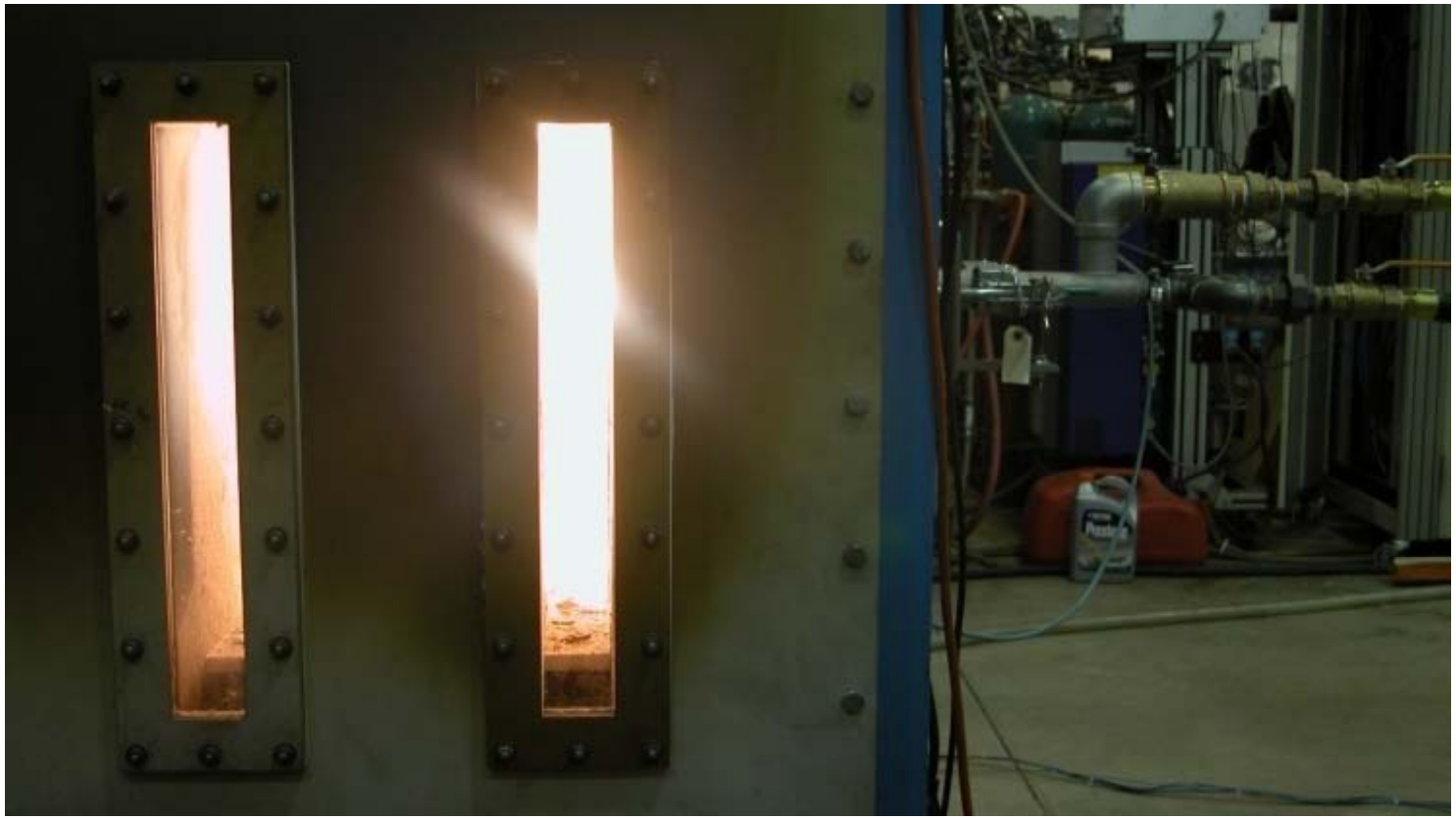
ThermJet-Adj-1, 2, 3 Cont



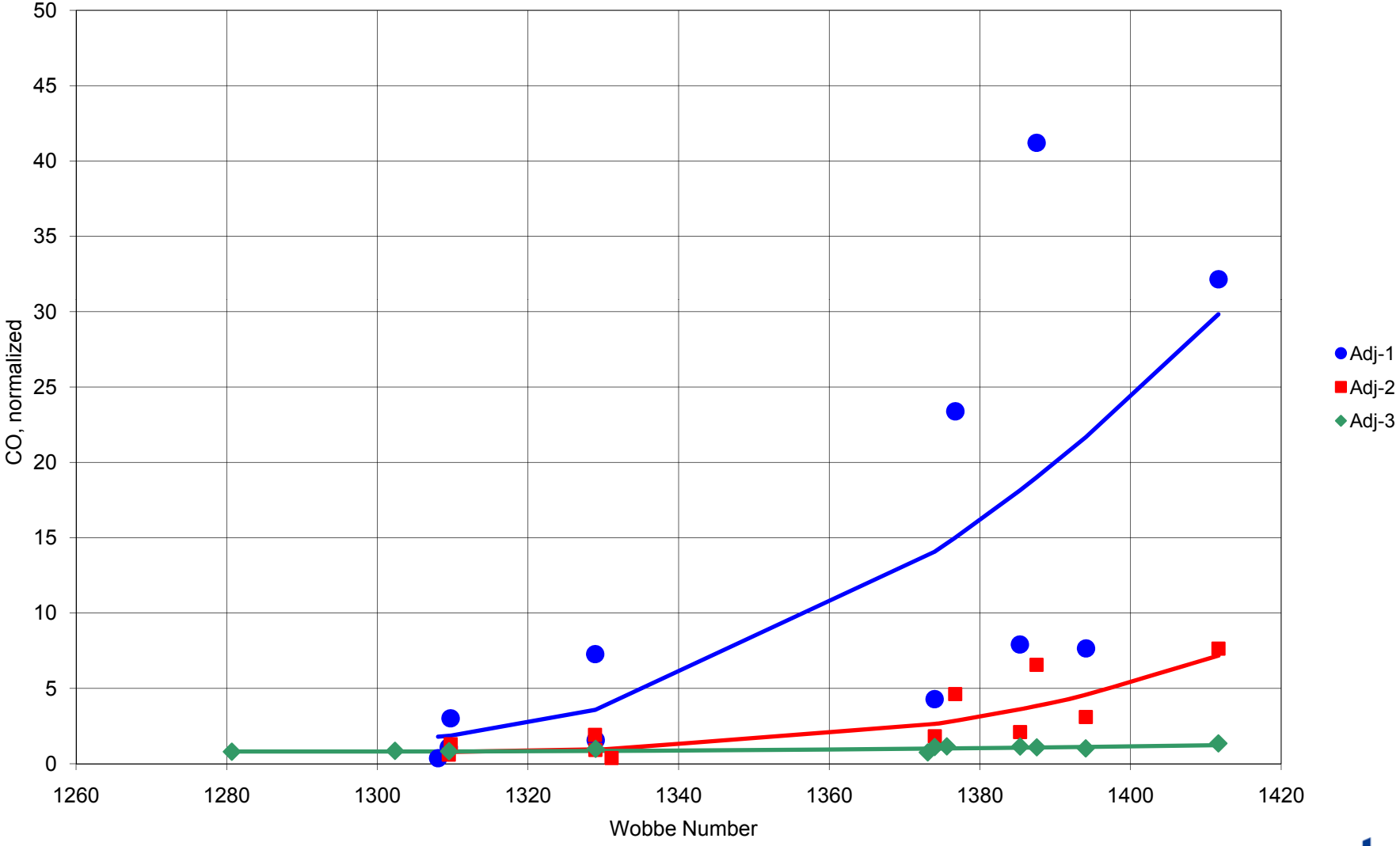
High Velocity Burner (ThermJet) - Continuous



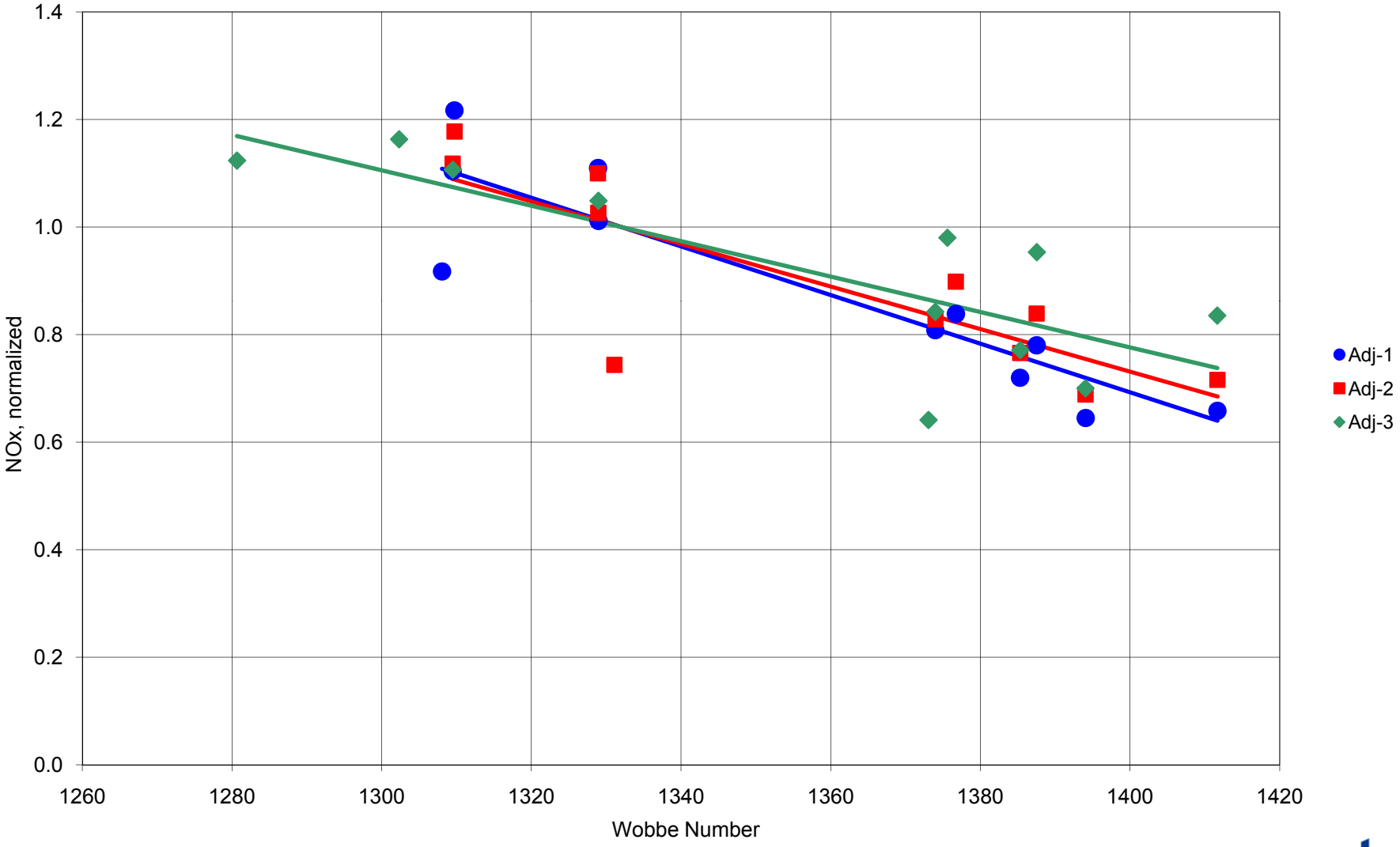
Oxygen-Gas Burner
Eclipse
Primefire 300
Glass furnaces



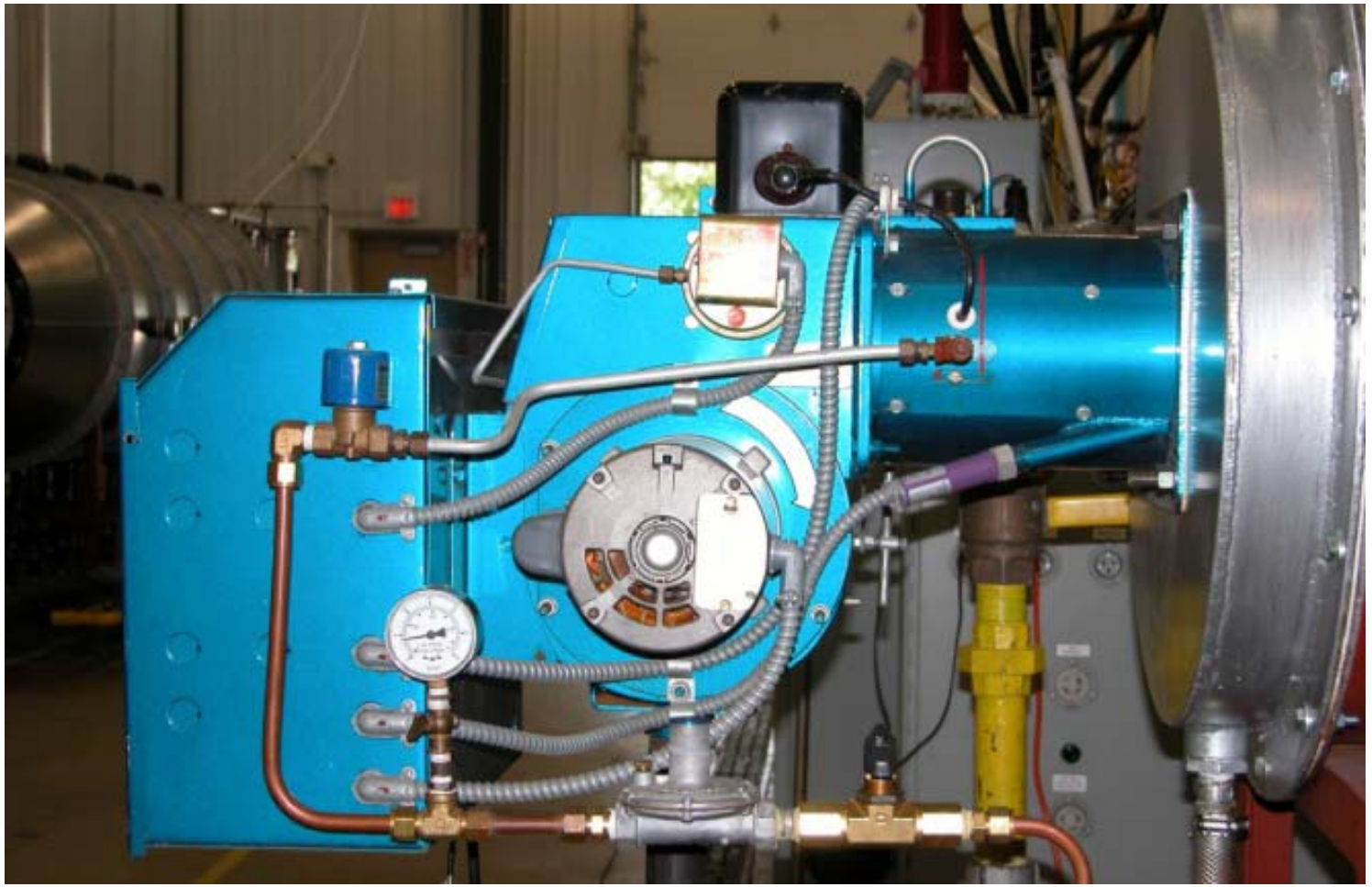
Oxy-Gas Burner Adj-1, 2, 3 Cont



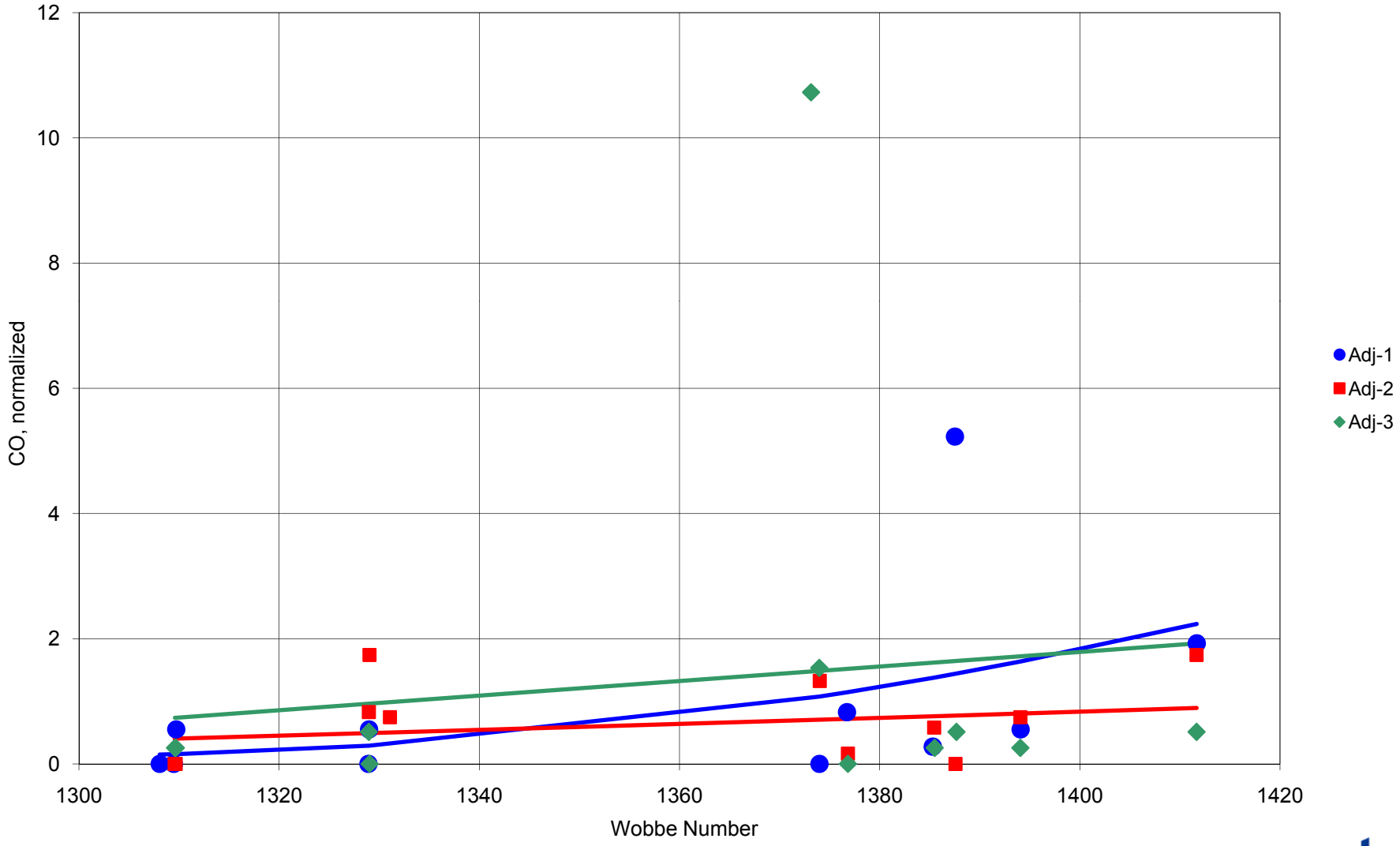
Oxy-Gas Burner - Adj-1, 2, 3 Cont



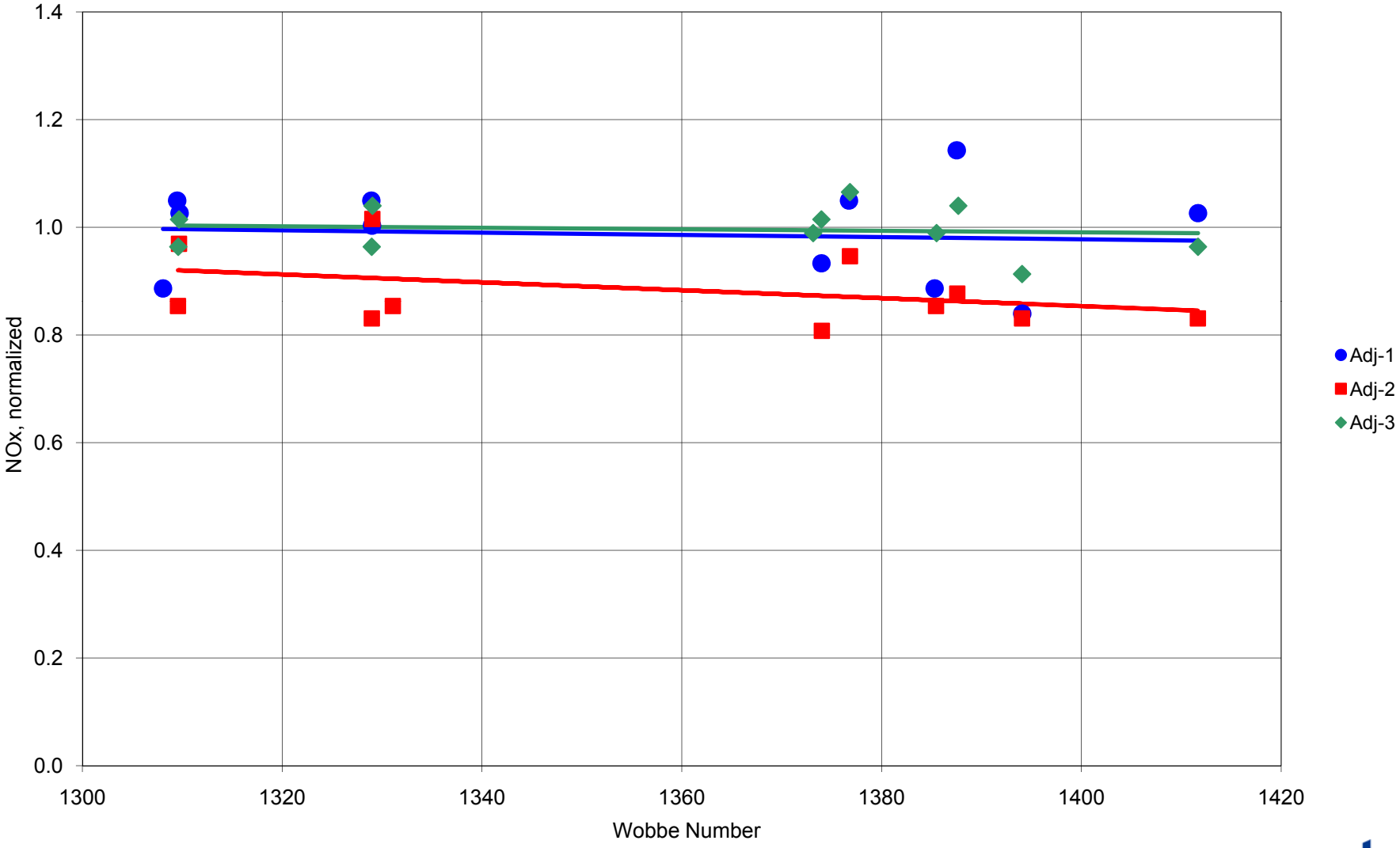
Boiler Burner - Power Flame – NVC Packaged System



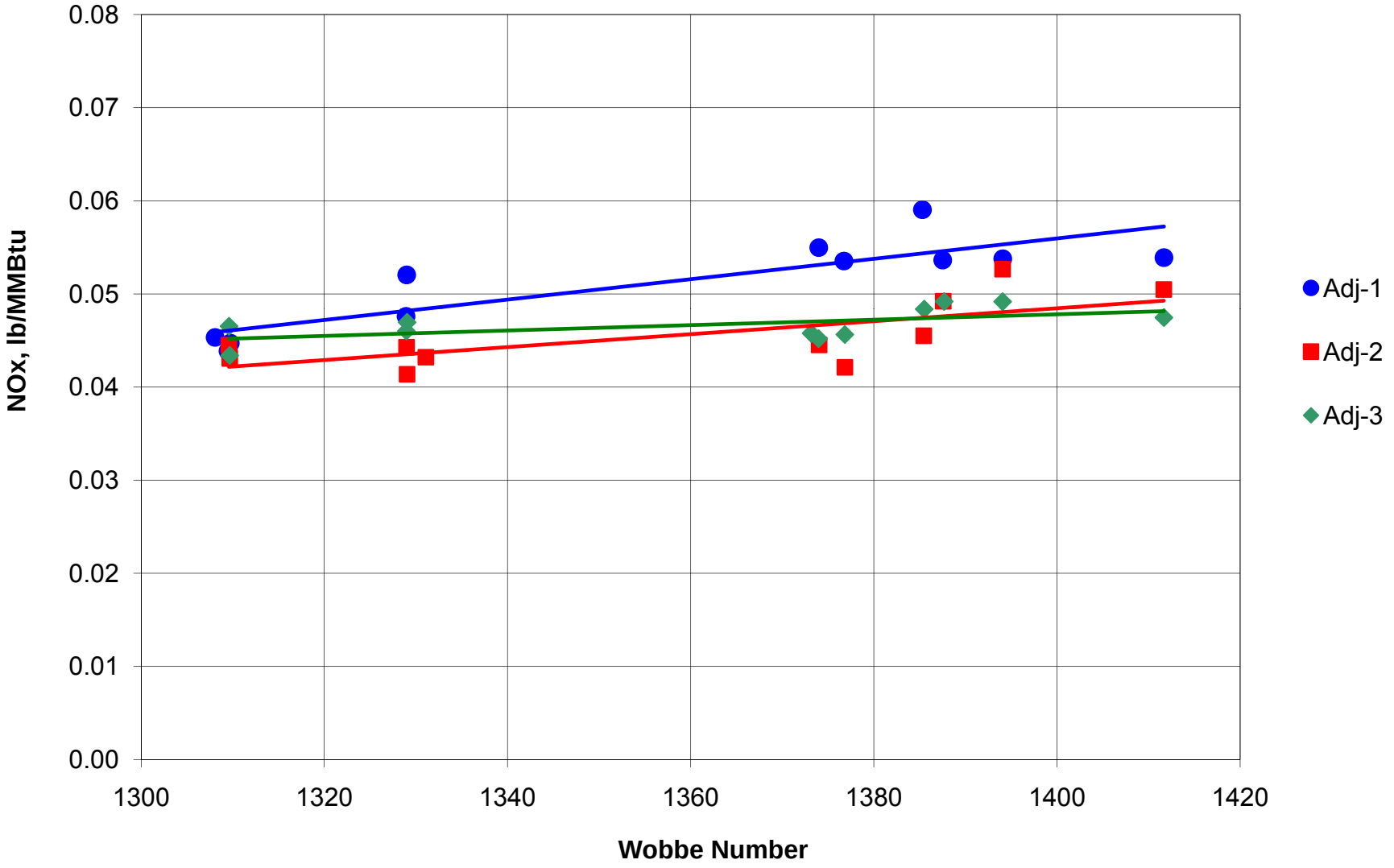
Power Flame - Adj-1, 2, 3 Cont



Power Flame - Adj-1, 2, 3 Cont



Boiler Burner (PowerFlame) - Continuous



Cleaver Brooks Low Emission Package Boiler

- 80-hp, 150-psig two-pass firetube steam boiler
- Cleaver Brooks low NOx burner – comes with the boiler
- HawkICS integrated control system (PLC)
- Parallel positioning system for fuel, air, and FGR flow

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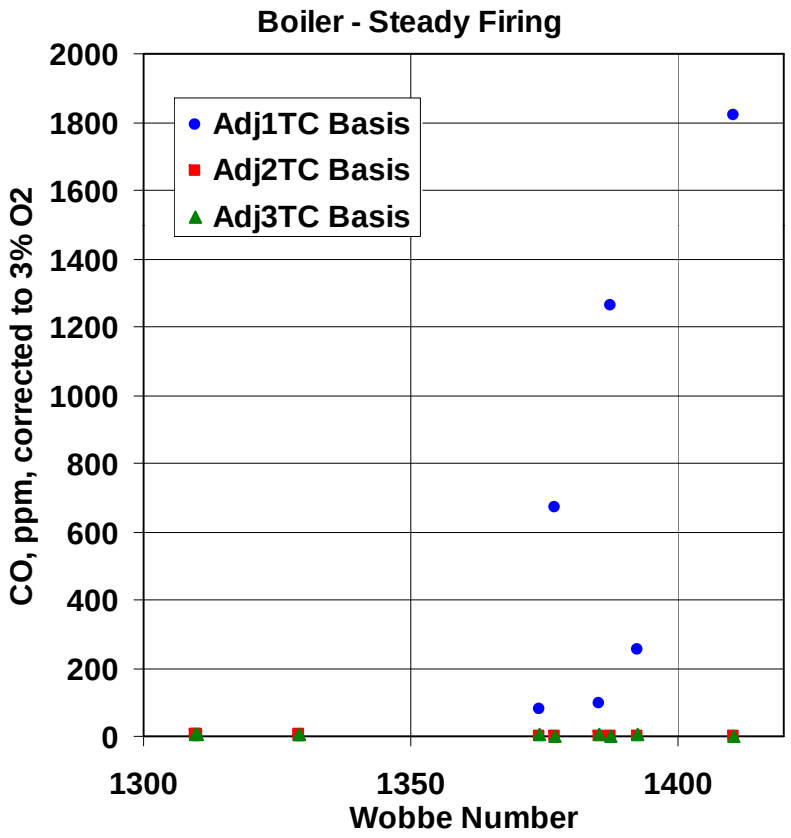
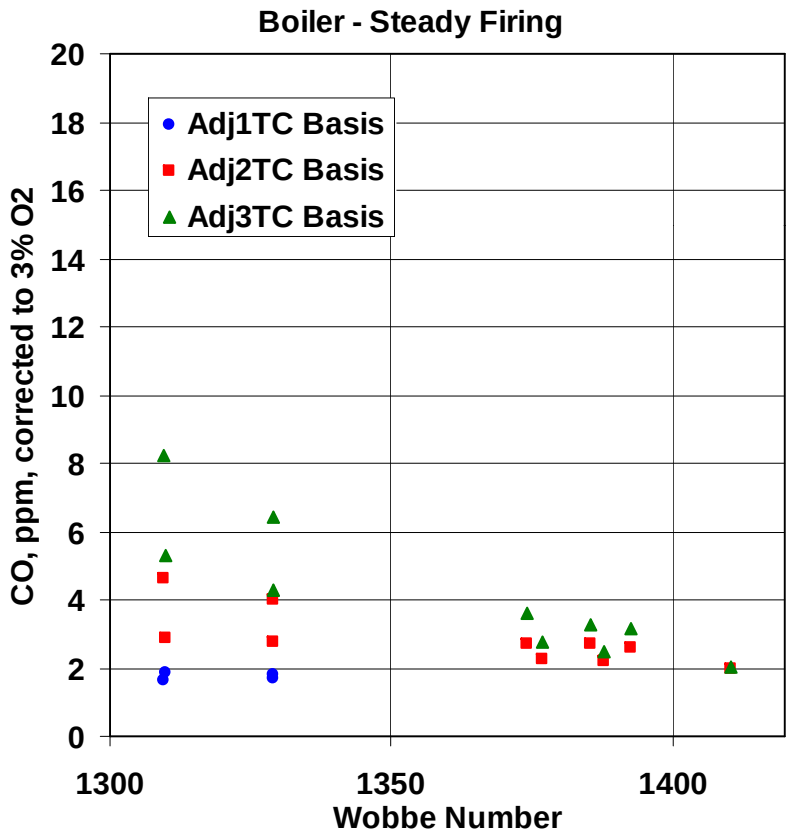
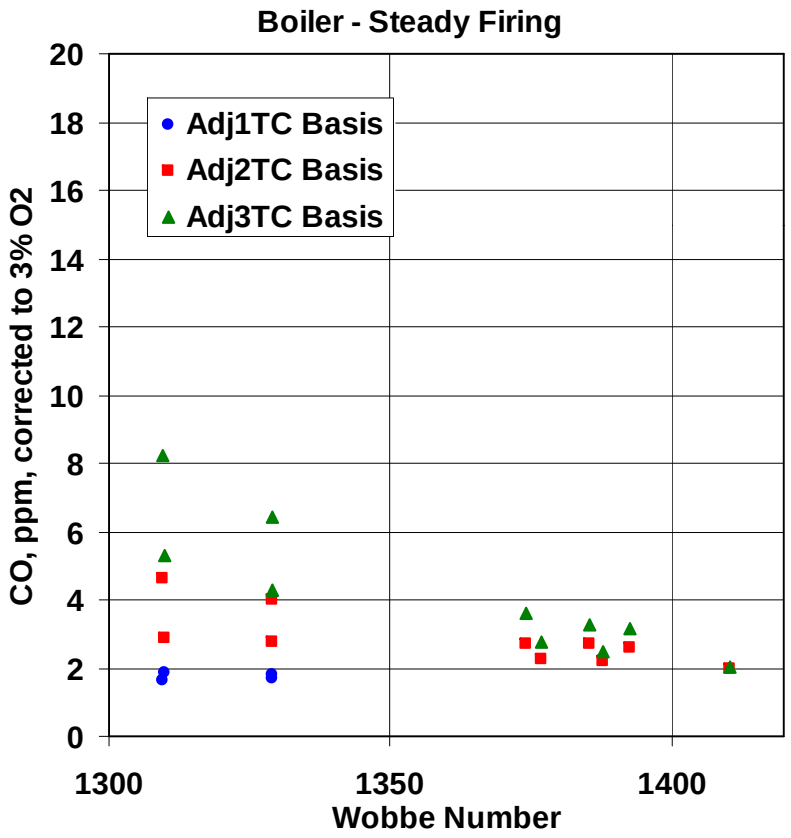
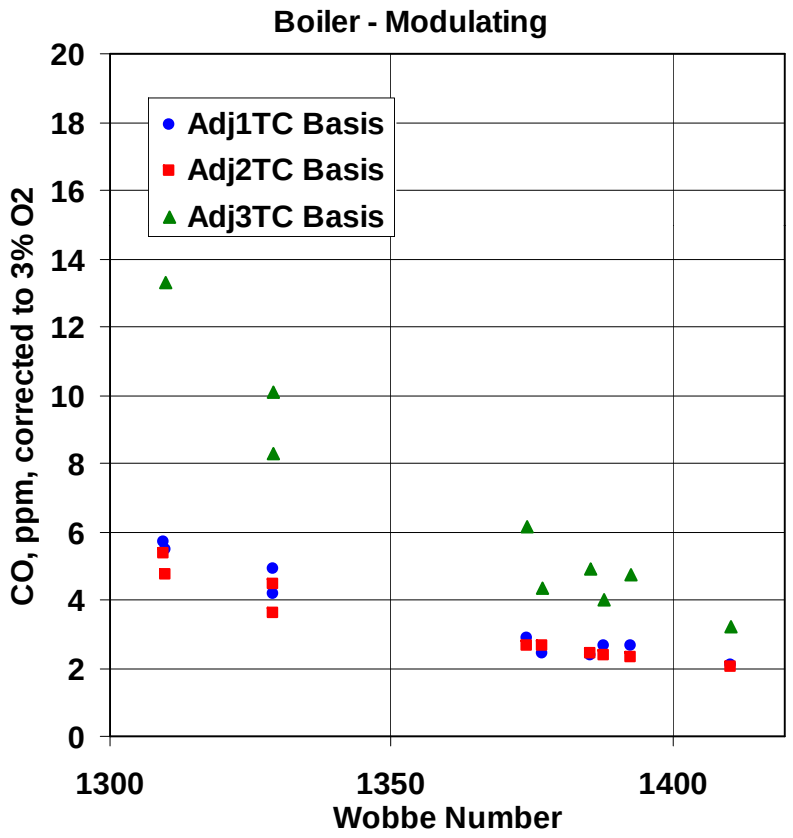
Cleaver Brooks Boiler Emissions



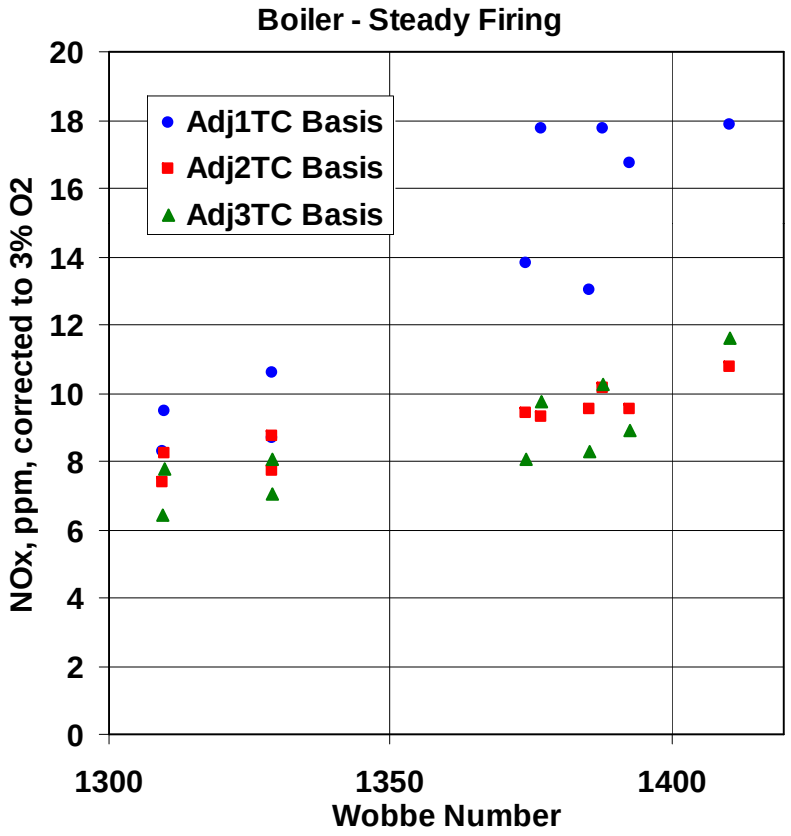


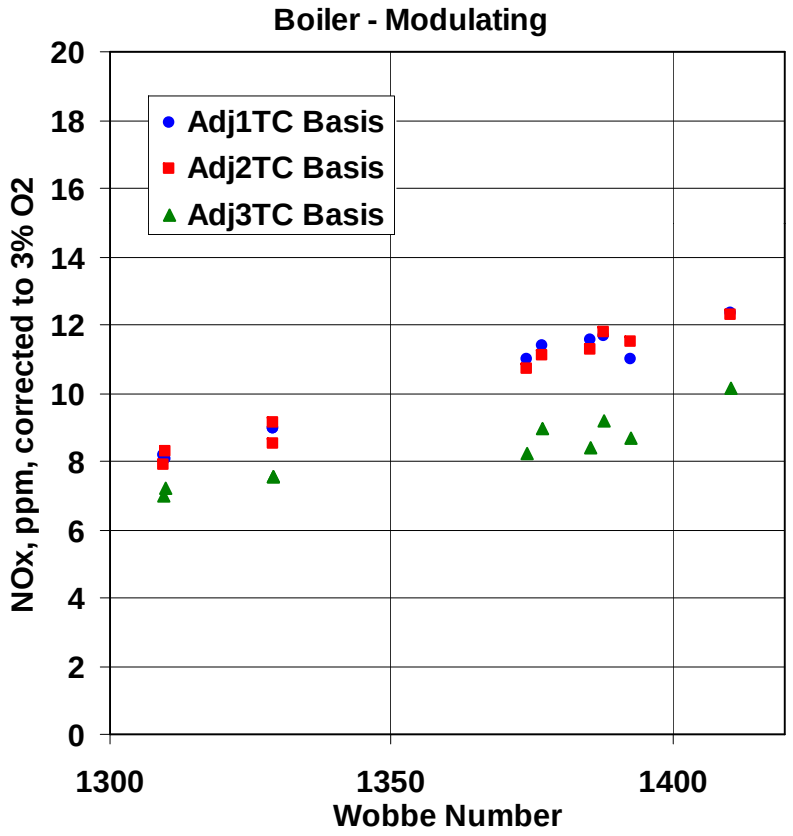
Cleaver Brooks Boiler Emissions





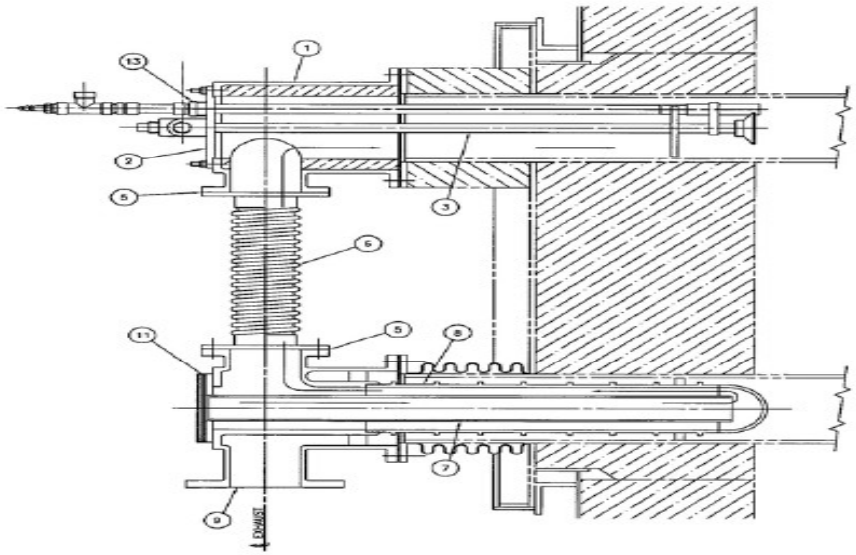
Cleaver Brooks Boiler Emissions





Bloom Recuperative Burner 2320 – Next Test

- Model 2320 with W-tube
- Multi-fuel capacity – natural gas, coke gas, butane, propane, oil #2
- Auto high-low modulation
- Annealing, galvanizing and silicon lines
- Air preheat up to 650F
- Nominal firing rate is 481,000 Btu/h



CSI (California Steel) Field Test

- Install parallel fuel supply line to burner
  - Natural gas mass flow meter
  - Mixing tee
    - Propane via mass flow controller
    - Nitrogen via mass flow controller
  - Limiting orifice for tuning
- Add thermocouples for exhaust and air preheat temperatures
- Tune burner for each of the three “adjust” gases, one at a time
  - Run at least five “substitute gases”

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Conclusions

- No industrial burners had ignition problems over the range of gases studied (1308-1425 W)
- Emissions (NOx, CO) can increase, decrease, or be unchanged for burners
- With proper tuning NOx for all burners at 1385 W can be equal to or lower than NOx when burner is tuned to 1332 W
- For burners using low oxidant to fuel ratios (radiant tubes, oxygen burners, low NOx boilers) higher W gas requires increased oxidant to avoid exponential increases in CO
- Many burners require no adjustments for NOx, CO
- Advanced controls can do needed tuning for many burners
- Data suggests simplified protocols can be devised for the remaining burners of concern

Testing Results

- IR burner
  - When tuned for Adj. 2 (1332 W) or adj. 3 (1375 W) – NOx and CO are unchanged over full 1300-1425 W range
- Radiant Tube burner
  - NOx decreases with higher W gas when tuned for all adjust gases from 1308 -1375 W
  - CO climbs exponentially with higher W gas if air to fuel ratio is not adjusted
- Linear burner
  - NOx increases as gas W increases, but when tuned for Adj. 3 (1375 W) NOx is the same as when the burner is tuned for Adj 2 (1332 W)
  - CO decreases as gas W increases. Tuning can lower CO

Testing Results

- High velocity burner
  - When tuned for Adj. 1 (1308 W) or Adj. 2 (1332 W), NOx is unchanged from 1308 to 1385 W
  - CO decreases with increasing gas W
- Oxygen burner
  - NOx decreases with increasing gas W, for each tuning
  - CO climbs exponentially with higher W gas if oxygen to fuel ratio is not adjusted
- Powerflame Boiler burner
  - NOx is nearly independent of gas W from 1308 to 1385 W, but tuning does affect the level of NOx
  - Wide CO variation, possibly due to mixing. But CO is much lower than for all other burners tested

Testing Results

- Cleaver Brooks Low-NOx boiler
  - NOx meets 9 ppmv target when tuned to a natural gas
  - NOx can increase significantly when gas is far away from tuning conditions
  - CO is very low except when air to fuel ratio becomes too low
  - Behavior under steady operating and modulating operating conditions is similar but not the same
  - No problems with ignition under any operating conditions tested

"Modeling Classes" of Emissions – Work in Progress

- Nitric Oxides (NO_X):
  - Normalization
    - *Firing rate*
    - *Wobbe number*
    - *Operation scheme*
  - Validation

Normalization done by Adjust 2 gas (Wobbe Number - 1332)
Being conducted across all industrial burners and gases tested

- Carbon Monoxide (CO)
  - Normalization
    - *Firing rate*
    - *Wobbe number*
    - *Operation scheme*
  - Validation
  - Oxygen compensation
    - *It is known that CO has a non-linear behavior vs oxygen content*

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Commercial Cooking Unit Selection

- GTI enlisted Carl Suchovsky , President of Gas Consultants, Inc. and Don Fisher of Fisher-Nickel, inc. to help select the commercial foodservice appliances
- We wanted to select representative appliances currently sold in California
- Appliances should represent technology commonly found in restaurants
- We wanted a good representation of the burner types found in food service equipment (atmospheric, infrared, powered and fan assisted burners)

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Commercial Cooking Unit Considerations

- We have contacted all of the manufacturers of the equipment selected, and they have all agreed to participate in the program
- One manufacturer declined to participate and we chose another manufacturer to replace them
- All of the appliances selected are currently on the California energy efficiency rebate website

Commercial Cooking Unit Testing

- All interchangeability testing will be conducted in the GTI Residential-Commercial laboratory
- Appliances will be loaned to GTI for testing – several are already available
- Testing protocols will be prepared and submitted to PAC members for review
- Typical emissions (CO, NOx) will be monitored, LBNL will assist with formaldehyde analyses
- Testing is planned to take place between August and December 2010

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Commercial Cooking Appliances Selected

Appliance	Manufacturer	Model	Notes
Fryer	Frymaster	FH155	infrared burner, exhaust fan
Fryer	Pitco	SG-14 or SSH55	atmospheric burner
Convection Oven	Blodgett	DFG-100Xcel	atmospheric burner, exhaust blower
Combi Oven	Cleveland	OGB-6.20	dual premixed powered burners

Commercial Cooking Appliances Selected

Appliance	Manufacturer	Model	Notes
Griddle	Vulcan	36RRG	atmospheric U-shaped burners
Griddle	Jade	JSO315	blue flame burner (cast iron open burners)
Range	Garland	G36-6R	33,000 Btu/h top burner
Steamer	AccuTemp	N6	stainless steel powered burner

Appliance Test Facility

Appliances for Testing

- Fryer
- Griddle
- Convection Oven
- Combi Oven
- Steamer
- Range

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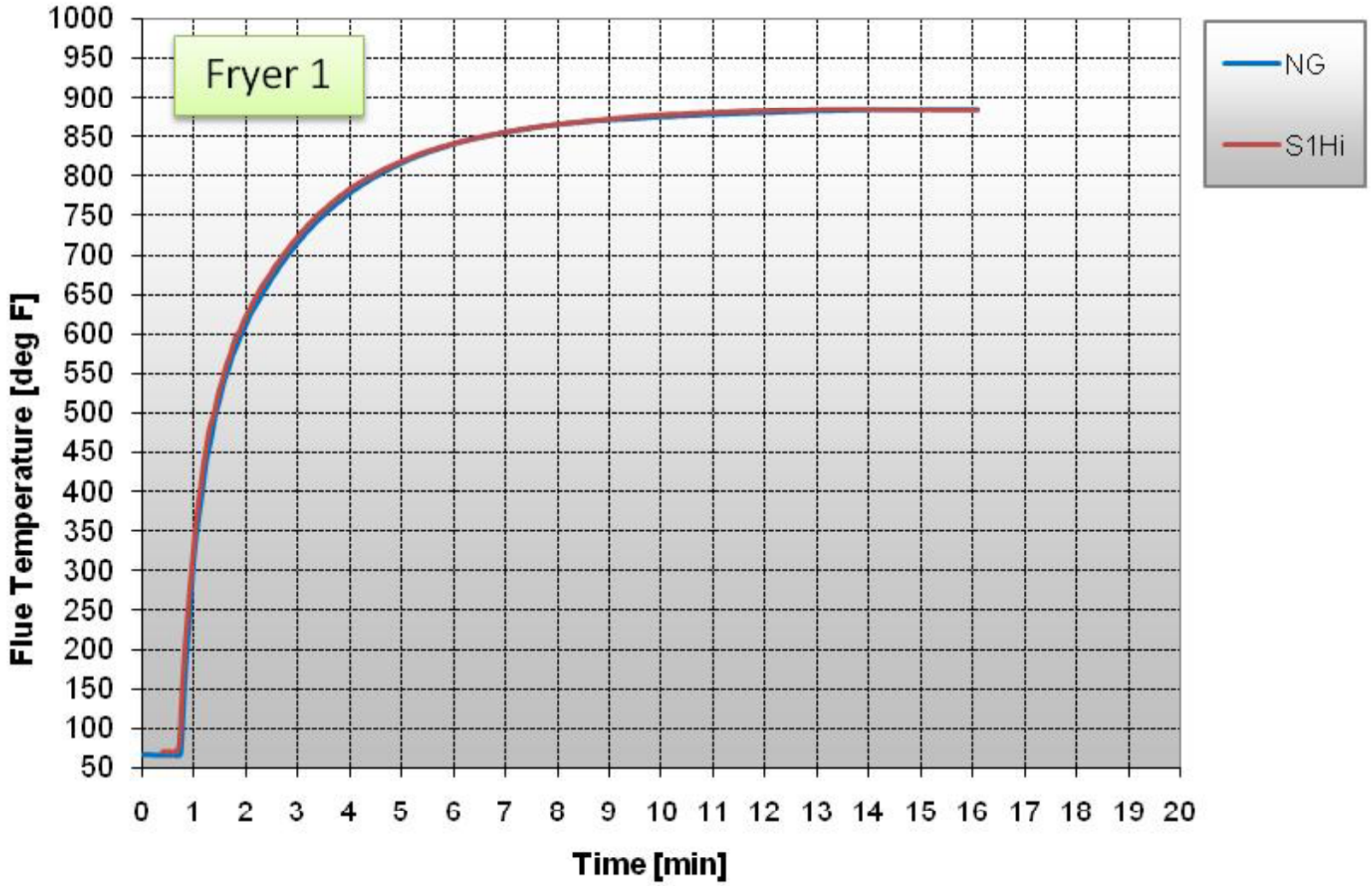
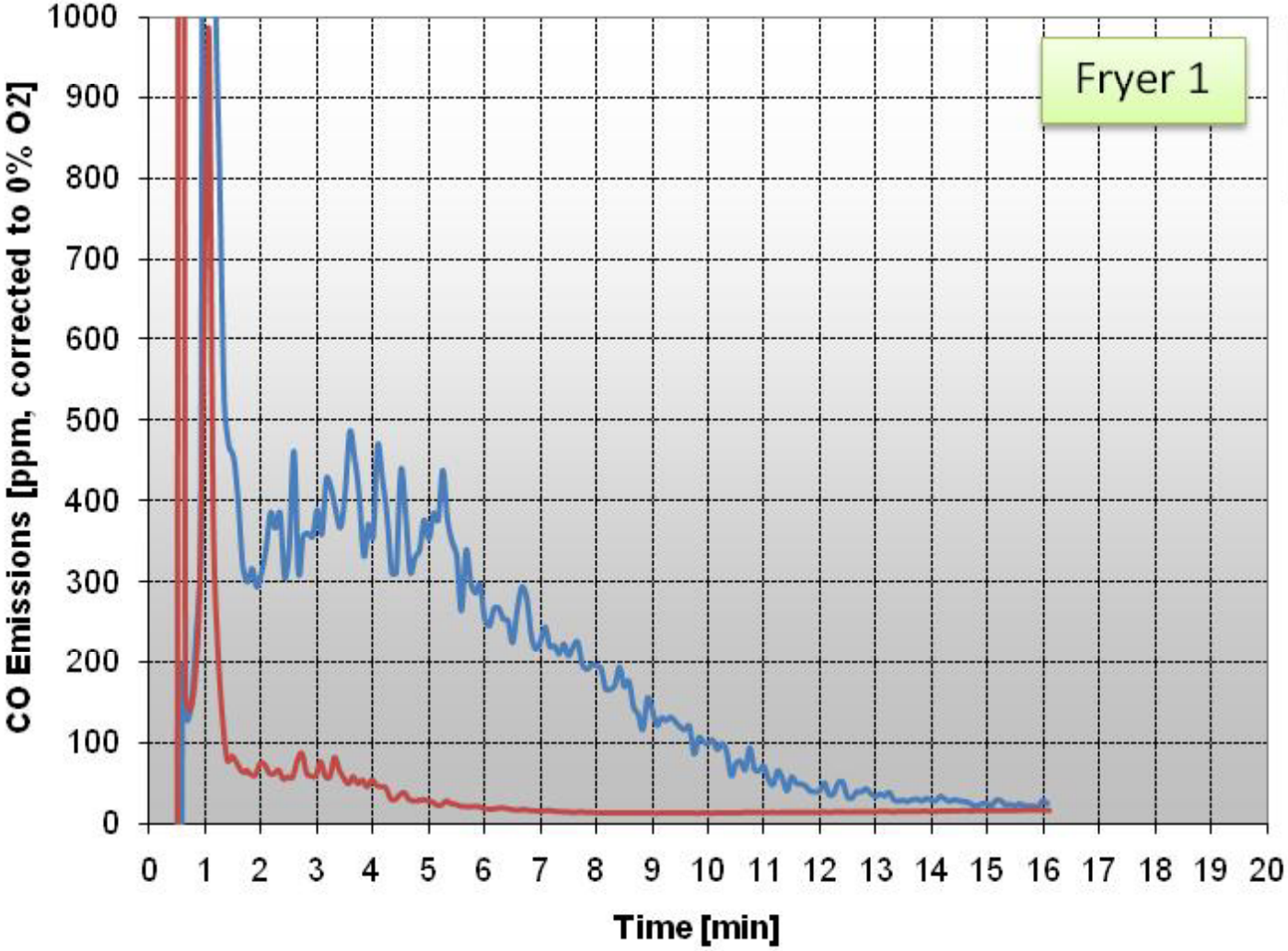
Fryer1: Flue Temperatures



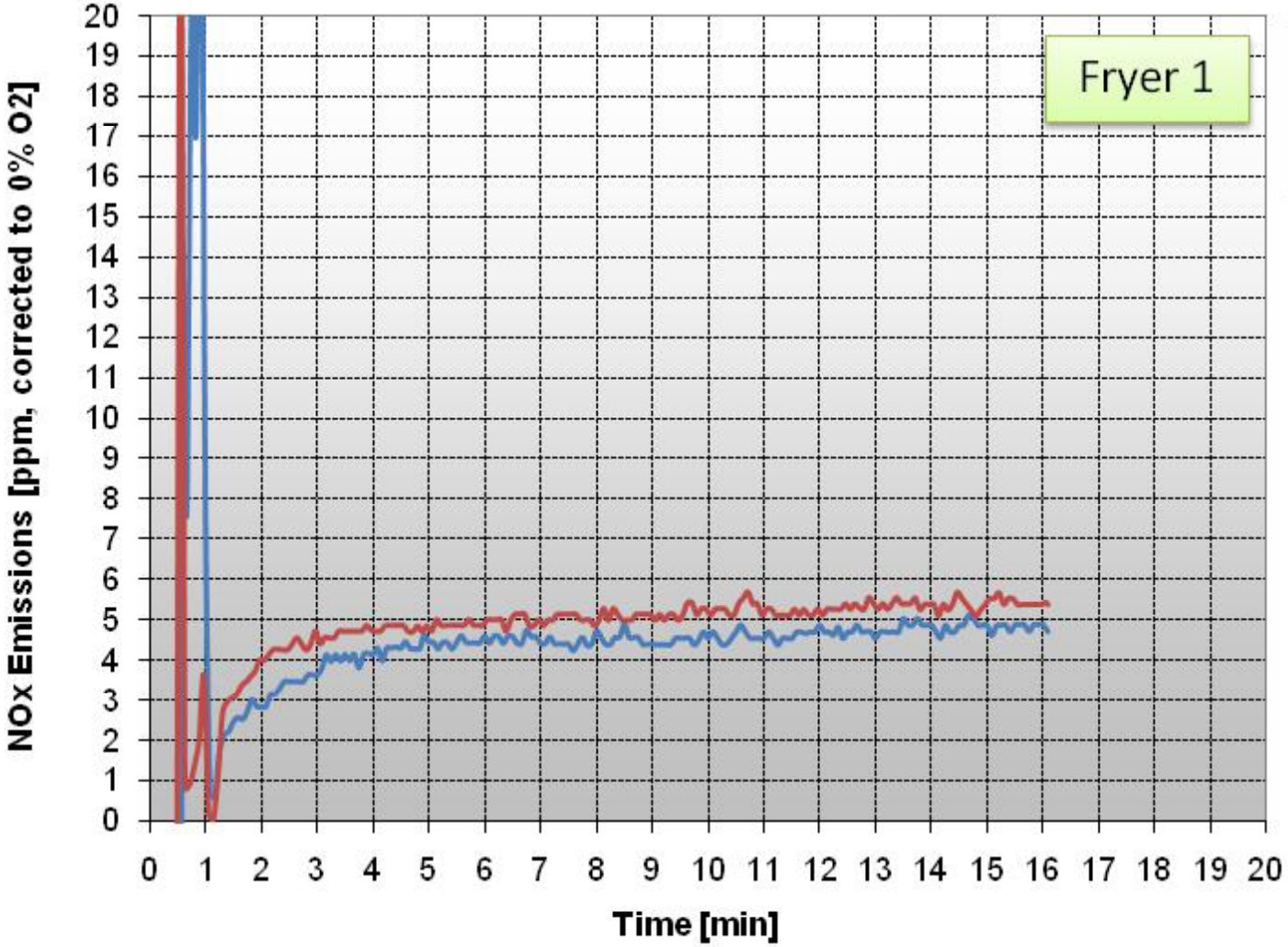
Fryer1: CO Corrected to 0% Oxygen – Not Corrected to Firing Rate



Transient CO increase during start-up

Unchanged CO after start-up

Fryer1: NOx Corrected to 0% Oxygen – Not Corrected to Firing Rate



No change in NOx after correcting for decrease in fuel volumetric rate of 8.8%

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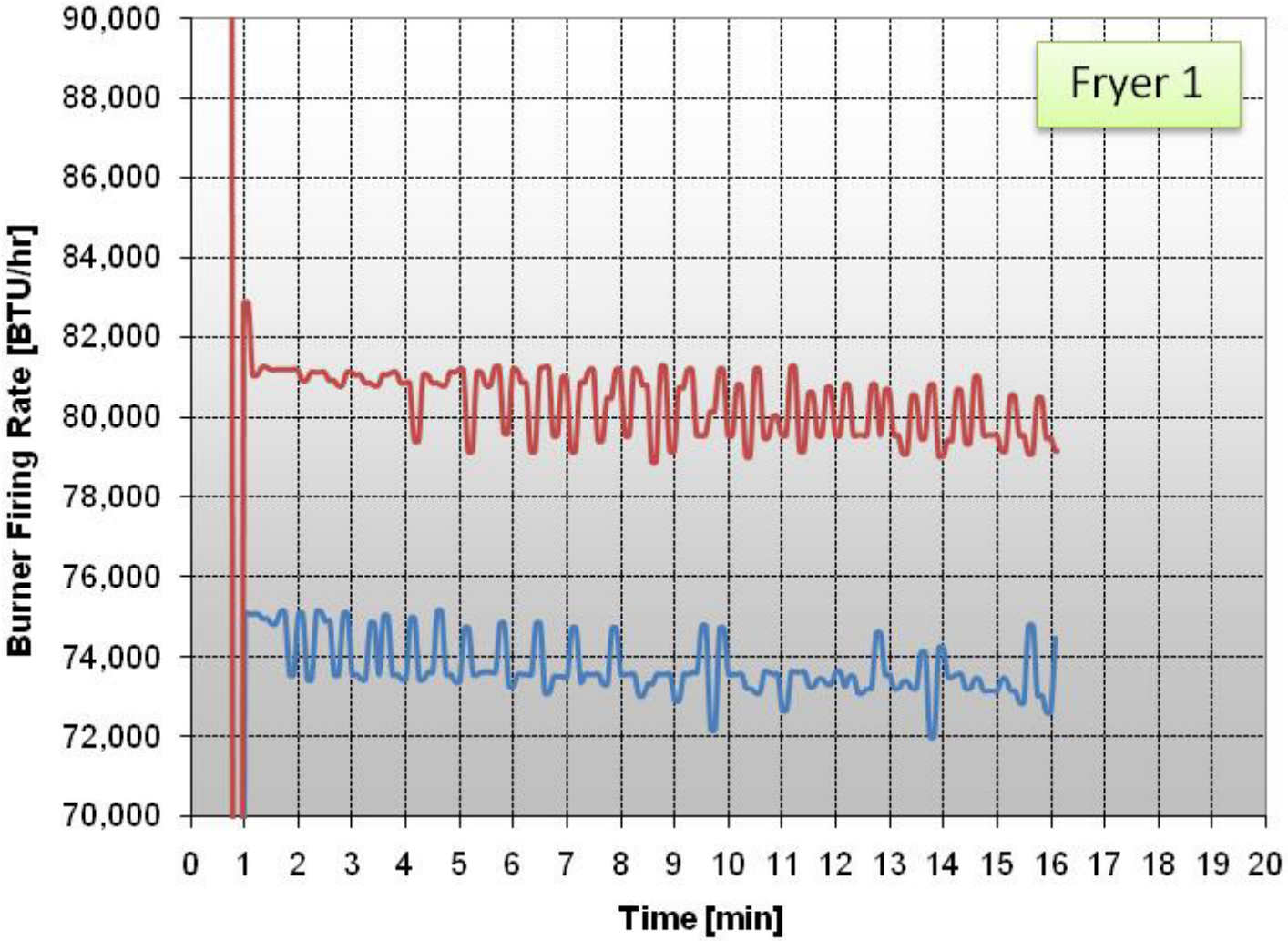
Fryer1: Burner Firing Rate – Constant Temperature



NG – 1305 W
S1H1 – 1385W
W increase – 6.1%

Fuel Savings 8.8%